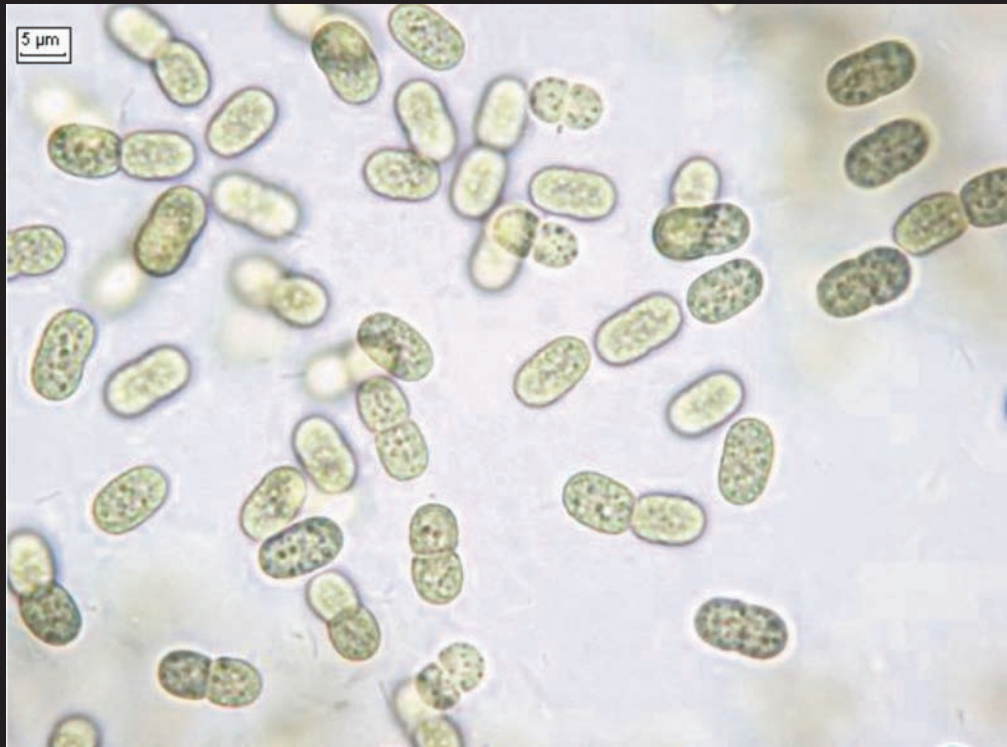


Handbook of Cyanobacteria

T. A. Sarma



Handbook of Cyanobacteria

This page intentionally left blank

Handbook of Cyanobacteria

T. A. SARMA
Formerly Professor of Botany
Department of Botany, Punjabi University
Patiala (Punjab), India



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

A SCIENCE PUBLISHERS BOOK

CRC Press
Taylor & Francis Group
6000 Broken Sound Parkway NW, Suite 300
Boca Raton, FL 33487-2742

© 2013 by Taylor & Francis Group, LLC
CRC Press is an imprint of Taylor & Francis Group, an Informa business

No claim to original U.S. Government works
Version Date: 20130227

International Standard Book Number-13: 978-1-4665-5941-7 (eBook - PDF)

This book contains information obtained from authentic and highly regarded sources. Reasonable efforts have been made to publish reliable data and information, but the author and publisher cannot assume responsibility for the validity of all materials or the consequences of their use. The authors and publishers have attempted to trace the copyright holders of all material reproduced in this publication and apologize to copyright holders if permission to publish in this form has not been obtained. If any copyright material has not been acknowledged please write and let us know so we may rectify in any future reprint.

Except as permitted under U.S. Copyright Law, no part of this book may be reprinted, reproduced, transmitted, or utilized in any form by any electronic, mechanical, or other means, now known or hereafter invented, including photocopying, microfilming, and recording, or in any information storage or retrieval system, without written permission from the publishers.

For permission to photocopy or use material electronically from this work, please access www.copyright.com (<http://www.copyright.com/>) or contact the Copyright Clearance Center, Inc. (CCC), 222 Rosewood Drive, Danvers, MA 01923, 978-750-8400. CCC is a not-for-profit organization that provides licenses and registration for a variety of users. For organizations that have been granted a photocopy license by the CCC, a separate system of payment has been arranged.

Trademark Notice: Product or corporate names may be trademarks or registered trademarks, and are used only for identification and explanation without intent to infringe.

Visit the Taylor & Francis Web site at
<http://www.taylorandfrancis.com>

and the CRC Press Web site at
<http://www.crcpress.com>

To my wife
Jaya
for
the inspiration, encouragement
and patience

This page intentionally left blank

Preface

I have been deeply fascinated by the cyanobacteria ever since my student days. As a teacher and researcher, I have always looked for a resource book that contains comprehensive information about cyanobacteria. Many universities have included cyanobacteria as a specialization at the post-graduate level. The travails faced by the research students in accessing literature are too diverse. Many of my colleagues are of the view that there is a necessity of a single reference book for research and teaching. 'Handbook of Cyanobacteria' is meant to fill such a role. A lot of new information has been generated consequent upon the publication of the first genome sequence of an autotroph *Synechocystis* sp. PCC 6803 and the understanding of every aspect of the biology of these organisms has undergone a sea change. This Handbook begins with a summary of the current knowledge on the taxonomy, phylogeny and evolution of cyanobacteria followed by the sequenced genomes, differentiation of akinetes and heterocyst. The mechanisms of cellular movements (gliding, swimming and twitching movements) exhibited by various cyanobacteria in order to adjust to their environmental niches and the operation of the circadian rhythms have been considered. The cyanobacterial symbiosis, cyanophages and cyanobacterial toxins are the other important areas covered followed by a discussion on stress responses (salinity, temperature, desiccation and oxidative). These ten important areas truly reflect the essential features of the biology of these organisms and also aptly justify this Handbook.

It has been quite an exhilarating work for me to sort out and read the literature (up to December, 2011) and present it in a simple language. The availability and the choice of illustrations had been quite demanding. I am grateful to the editors/publishers of the Journals of Open Access category and to the individual scientists who permitted me to use the figures that appeared in the research papers published by them in these Journals. Many of the illustrations have been provided by individual scientists and Government Agencies from their websites. All the illustrations are duly acknowledged in the captions provided with the respective figures.

At this juncture, I express my deep sense of gratitude to a host of my teachers, colleagues and students who richly contributed to my professional growth. Institutional support from Punjabi University is gratefully acknowledged.

I earnestly hope that this Handbook adequately serves the purpose for which it is intended and will be useful to students as well as teachers. I would greatly appreciate receiving suggestions for general improvement of this Handbook.

T. A. SARMA
(ta.sarma@gmail.com, tangiralas.com)
(May, 2012)

This page intentionally left blank

Contents

<i>Dedication</i>	v
<i>Preface</i>	vii
1. Taxonomy, Phylogeny and Evolution	1
2. Genomes	76
3. Akinetes	140
4. Heterocyst	165
5. Movements	281
6. Circadian Rhythms	303
7. Symbiosis	336
8. Cyanophages	417
9. Cyanobacterial Toxins	487
10. Stress Responses	606
<i>Index</i>	755
<i>Color Plate Section</i>	767

This page intentionally left blank

TAXONOMY, PHYLOGENY AND EVOLUTION

I. TAXONOMY	1
II. PHYLOGENY	13
1) 16S rRNA gene	
2) Molecular techniques based on 16S rRNA gene	
3) 16S rRNA gene sequencing in cyanobacteria	
4) Diversity of cyanobacteria determined on the basis of molecular markers	
5) The species concept in bacteria and cyanobacteria	
III. EVOLUTION OF BACTERIA AND CYANOBACTERIA	50
The root of the TOL	
IV. THE OTHER SIDE OF THE COIN	59

I. TAXONOMY

A classification provides a platform to identify a particular organism to the level of species. The art of classification is known as taxonomy and phylogeny helps to draw evolutionary relationships between the organisms classified. So a phylogenetic system of classification serves a better purpose for classification as well as inferring evolutionary relationships. The earliest taxonomic treatises considered cyanobacteria as an algal group under the general name blue-green algae (Thuret, 1875; Bornet and Flahault, 1888; Gomont, 1892). Traditionally thus, the blue-green algae have been classified along with eukaryotic algae under the International Code of Botanical Nomenclature (ICBN). As per rules of ICBN, a type species has to be deposited in a recognized Herbarium either in a dried state or fixed algal material. Due to the limitation in the availability of pure culture strains and the paucity of information on their biochemical and genetic features, the earlier workers depended mostly on morphological characteristics. Due to the absence of membrane-bound cell

organelles, the blue-green algae were considered closer to bacteria (Cohn, 1872, 1875). Subsequent to the publication of taxonomic keys on heterocystous forms (Bornet and Flahault, 1888) and the Oscillatoriaceae (Gomont, 1892), a comprehensive account on the taxonomy of these organisms has been presented by Geitler (1932) wherein 145 genera encompassing 1300 species have been classified into 20 Families under three Orders. The “Geitlerian” approach provided new impetus for a number of taxonomists to classify them (Fritsch, 1945; Drouet and Daily, 1956; Golubic, 1967; Bourelly, 1970 and many others) from time to time.

Drouet and Daily (1956) revised Geitler’s classification and brought down the number of genera to 24 with 62 species based on their observations on the blue-green algae collected from all over the world. The taxonomic criteria developed for identification have been based on morphological features and they further attributed the diversity in morphology due to the existence of ecophenes or ecotypes. According to them, the blue-green algal species is highly polymorphic and the phenotypic changes lack a genetic basis. That is polymorphism is assumed to be purely phenotypic. The ecophenes thus represent form-variations caused by environmental factors rather than due to genetic differences. Thus the species concept envisaged by Drouet predicts that a particular species should be morphologically identical when grown under the same environmental conditions and shows a similar change in morphology with changing environmental conditions while at the same time the genotype remains unchanged. On the basis of taxonomic keys available from time to time (Geitler, 1932; Drouet and Daily, 1956; Desikachary, 1959; Drouet, 1981; Komárek and Anagnostidis, 1989), a number of workers enumerated the cyanobacterial flora from wide variety of locations and habitats from all over the world.

The classification proposed by Fritsch (1945) has been mainly based on morphological characters. Of the five orders recognized, three have been placed together on the basis of absence of hormogones (Chroococcales, Chamaesiphonales and Pleurocapsales) and the other two Orders *Nostocales* and *Stigonematales* that form the hormogones have been placed together. Chroococcales are characterized by unicellular or colonial (commonly palmelloid) forms that multiply by cell division and by endospore formation. The members included in the Order Chamaesiphonales are unicellular or colonial epiphytes or lithophytes exhibiting marked polarity and reproduce by the formation of endospores or exospores. The Pleurocapsales comprise of heterotrichous filamentous types without heterocysts and reproduce by the formation of endospores. The members of Nostocales are either non-heterocystous or heterocystous filamentous forms. Some of these show false-branching. Multiplication is by means of hormogones, hormocysts and akinetes. Order Stigonematales comprises of heterotrichous filamentous types that exhibit true branching and possess heterocysts. The presence of pit-connections between the cells is another characteristic feature of these forms. The multiplication is by hormogonia, hormocysts and more rarely by akinetes. A few representative types of cyanobacteria identified on the basis of traditional taxonomic keys have been presented in Figs. 1 to 8.

A classification of cyanobacteria under ICBN has been proposed (Anagnostidis and Komárek, 1985) and revised (Komárek and Anagnostidis, 1989) that took into account the Bacteriological code as well. In this classification they recognized four orders- Chroococcales, Oscillatoriales, Nostocales and Stigonematales, which are further subdivided into families, subfamilies, genera and species. They emphasized that the taxonomic keys developed by them would be greatly helpful for ecologists to study the diversity of cyanobacteria from their natural habitats. Many objective features and characteristics for distinguishing various genera and species have been defined by them. Due to the application of both botanical and bacteriological criteria, an attempt has been made to reconcile the differences between the botanical and bacteriological codes. The taxonomic criteria based on botanical code included cell morphology, cell division, polarity, methods of false-branching, tapering

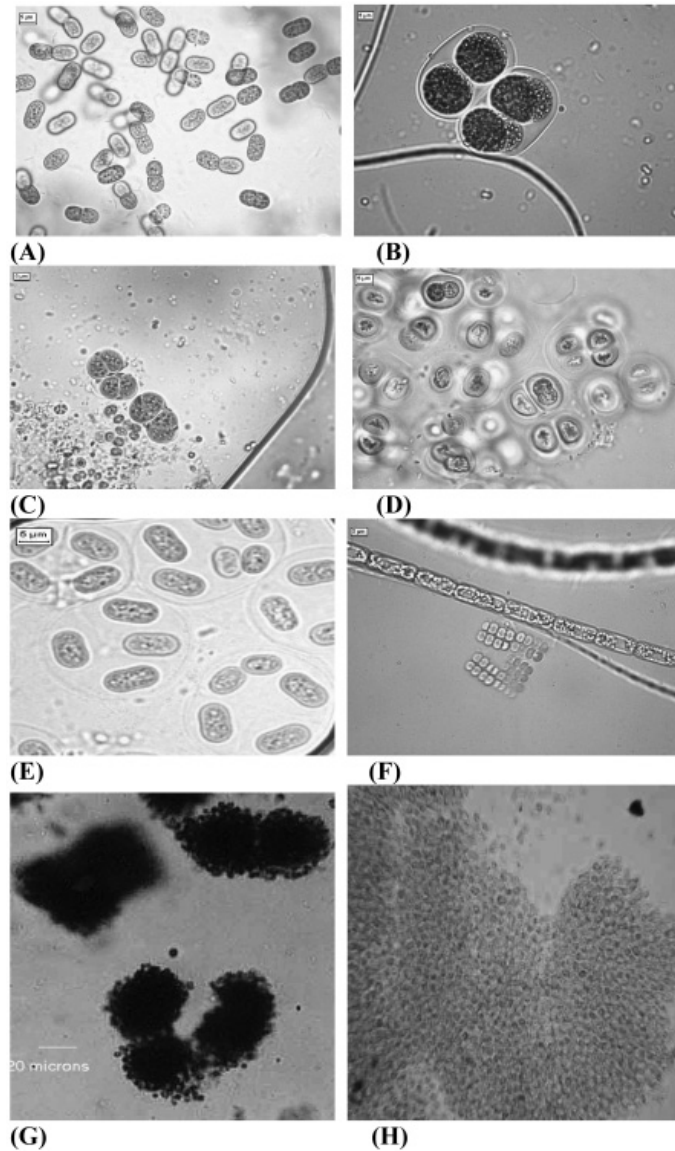
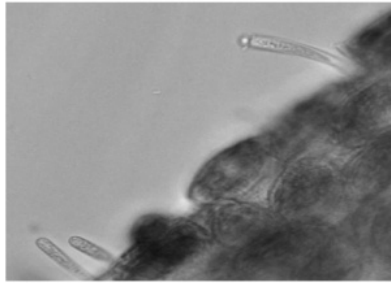
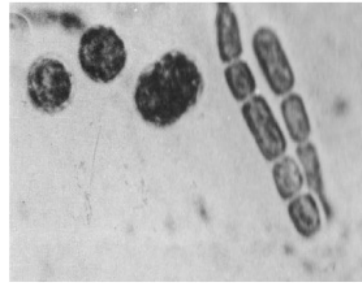


Figure 1: Members of Chroococcales. *Aphanothece* sp. (A), *Chroococcus* sp. (B and C), *Gloeocapsa* sp. (D), *Gloeotheca* sp. (E), *Merismopedia* sp. (F), colonies of *Microcystis* sp. (G), colony of *Microcystis aeruginosa* (H). Magnification bar in A to F represents 5 μ m, G 20 μ m and H x100. Pictures A to F courtesy G. L. Tiwari, Department of Botany, University of Allahabad, Allahabad-211002, India. (G) Courtesy Roger Burks (University of California at Riverside), Mark Schneegurt (Wichita State University) and Cyanosite (www-cyanosite.bio.purdue.edu). (H) Courtesy Jens Dahlmann (Friedrich Schiller University, Jena), Mark Schneegurt (Wichita State University) and Cyanosite (www-cyanosite.bio.purdue.edu).

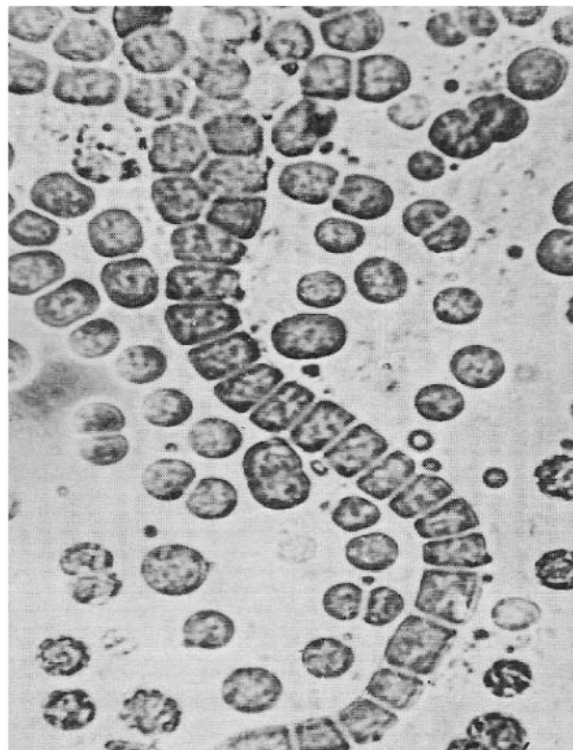
and hormogonia formation. Furthermore, they also used information obtained from bacteriological methods including molecular markers when required. The concomitant application of both ICBN and bacteriological code has resulted in the proper classification of this group (Garcia-Pichel *et al.*, 1998). However, Anagnostidis and Komárek (1988) cautioned that the re-classification of cyanobacteria



(A)



(B)



(C)

Figure 2: Members of Chamaesiphonales. *Chamaesiphon* sp. (A), *Stichosiphon indica* in cultures, two sporangia juxtaposed on agar plates (B), a sporangium releasing baeocytes in two rows from liquid cultures (C). Magnification of pictures (B) and (C) at $\times 1125$ and $\times 675$, respectively. Picture A courtesy Mark T. Aubel, GreenWater Laboratories/CyanoLab, 205, Zeagler Drive, Suite 302, Palatka, Florida 32177, USA. (http://www.greenwaterlab.com/photo_algal.htm). Pictures B and C are from Sarma (1981).

is difficult for a number of reasons because for example (i) traditional taxonomic criteria were developed over a century ago and were predicated on characters such as false-branching and sheath characteristics; (ii) the morphology of cyanobacteria is largely influenced by environmental factors;

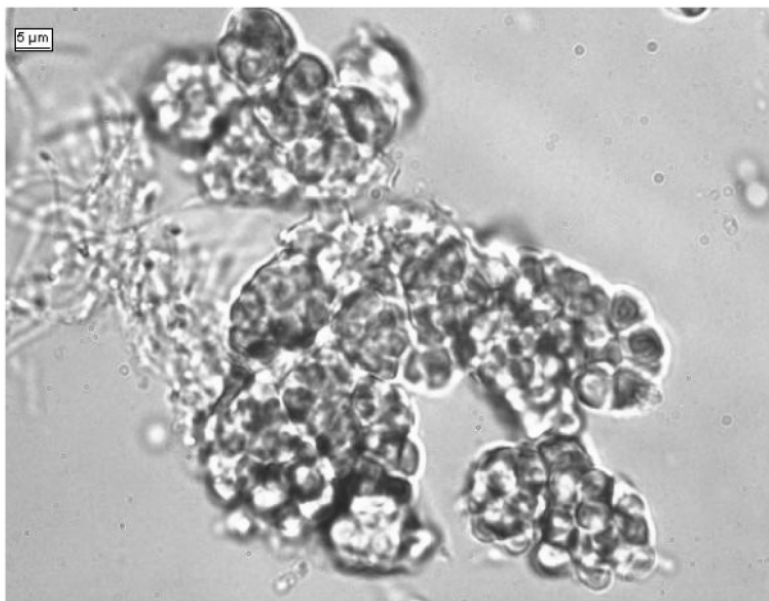


Figure 3: *Pleurocapsa* sp. from nature. Magnification bar represents 5 µm. Picture courtesy G. L. Tiwari, Department of Botany, University of Allahabad, Allahabad-211002, India.

(iii) the genetic diversity of collected strains within a culture may be decreased by selective culturing conditions; (iv) the species concept depended on the taxonomist and (v) the conservative approach of a number of taxonomists to adopt the new molecular methods. A number of proposals have been made for unification of nomenclature in case of botanical and bacteriological codes (Oren, 2004; Oren and Tindall, 2005; Hoffmann *et al.*, 2005).

Hoffmann *et al.* (2005) presented a classification scheme under ICBN on a polyphasic approach by taking into account morphological, ultrastructural, ecological and genetic relationships (mainly 16S rRNA gene sequences). This is an attempt to merge the Botanical as well as Bacteriological Codes. The Cyanobacteria are given the rank of a Class and designated them as Cyanoprokaryota with three sub-classes Synechococcineae, Oscillatorineae and Nostocineae. The Synechococcineae with two orders Synechococcales and Pseudoanabaenales consists of both coccoid and filamentous forms, respectively. The second sub-class Oscillatorineae comprises coccoid (Chroococcales) and filamentous forms (Orders Phormidiales and Oscillatoriales). The unification of heterocystous cyanobacteria into one sub-class Nostocineae with a single order Nostocales is a unique feature. The inclusion of Prochlorophyta in cyanobacterial classification system and the absence of distinction into coccoid and filamentous forms at the highest sub-class level are the highlights of this classification. The distinction into sub-classes is based on arrangement of thylakoids and the presence of differentiated cells. Chroococcales with unicellular or colonial members are characterized by radial arrangement of thylakoids. The non-heterocystous filamentous forms have been divided into three orders based on the nature of filaments and the arrangement of thylakoids. The Oscillatoriales possess large filamentous forms with radial arrangement of thylakoids while Pseudoanabaenales consist of thin filamentous forms in which the thylakoids are arranged parallel to the cell surface. The order Nostocales possesses filamentous, heterocystous, unbranched and branched members.

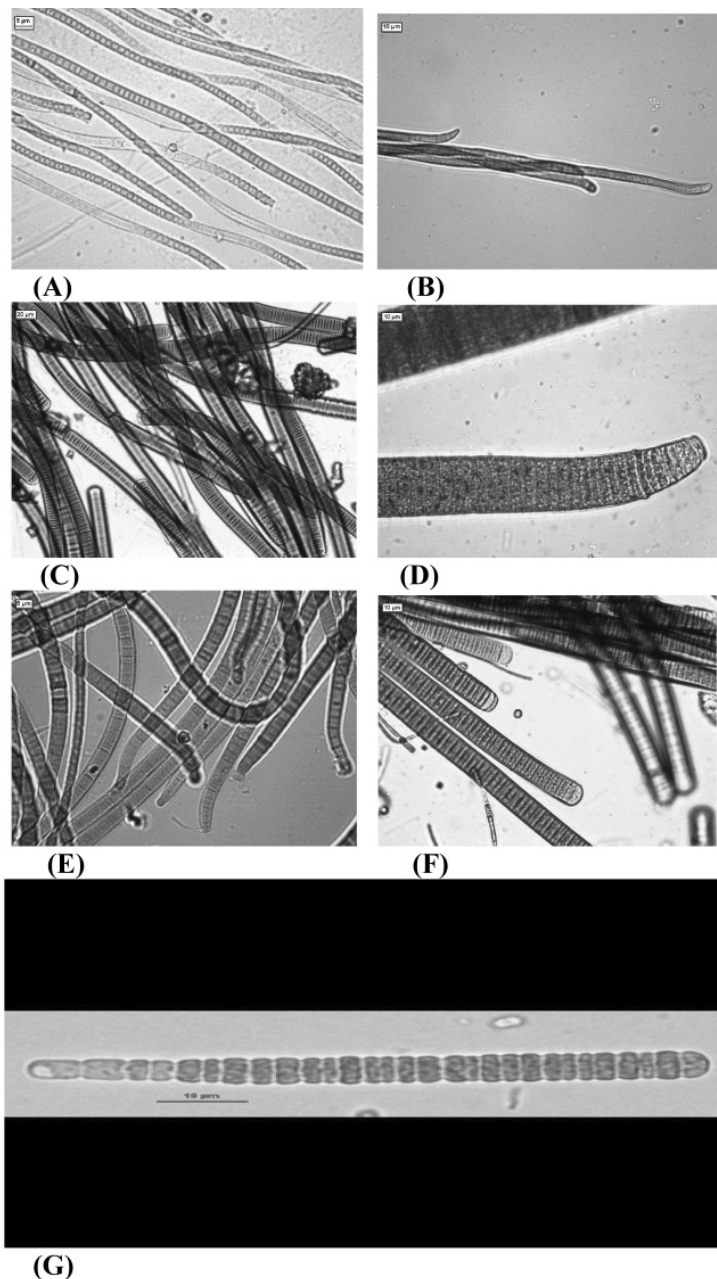


Figure 4: Representatives of Nostocales. *Geitlerinema* spp. (A and B), *Lyngbya* sp. (C), and *Oscillatoria* spp. (D, E and F), *Trichodesmium* sp. (G). Magnification bar represents 5 µm (A) and (E), 10 µm (B, D, F and G), and 20 µm (C). Pictures A to F courtesy G. L. Tiwari, Department of Botany, University of Allahabad, Allahabad-211002, India. Picture (G) courtesy P. Znachor, Laboratory of Phytoplankton Ecology, Institute of Hydrobiology, Biology Centre ASCR, Na Sádkách , 37005 České Budějovice, Czech Republic. www.FytoPlankton.cz.

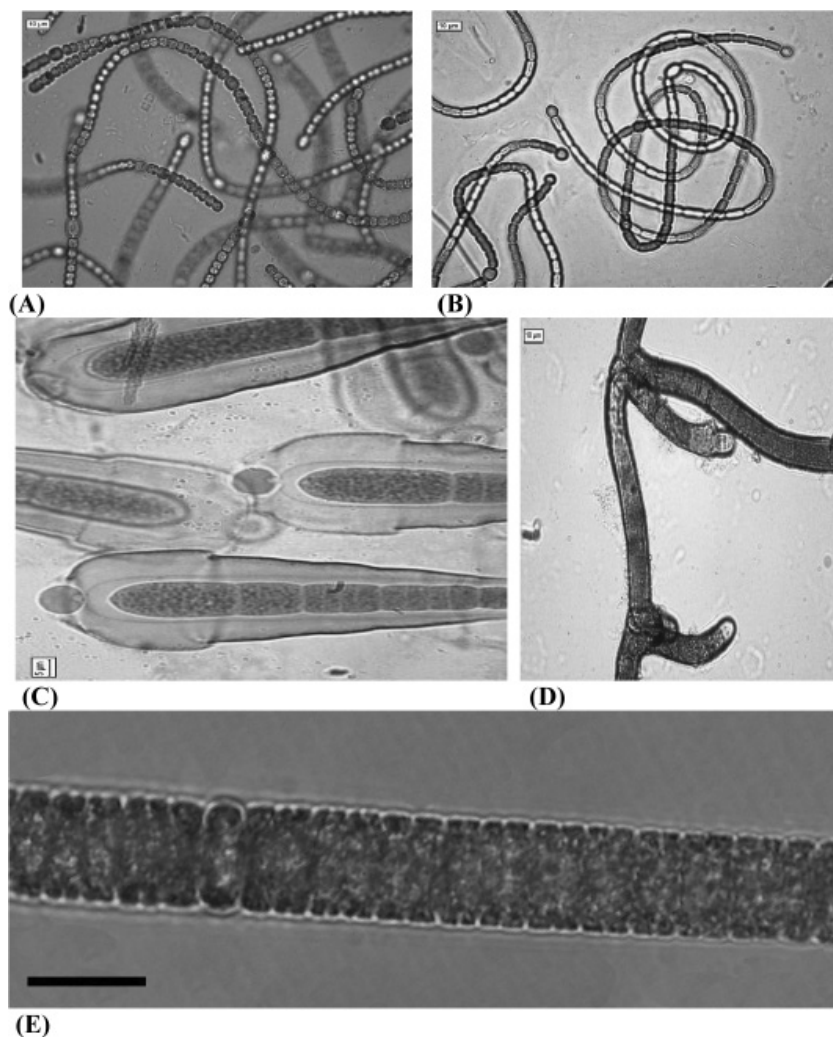
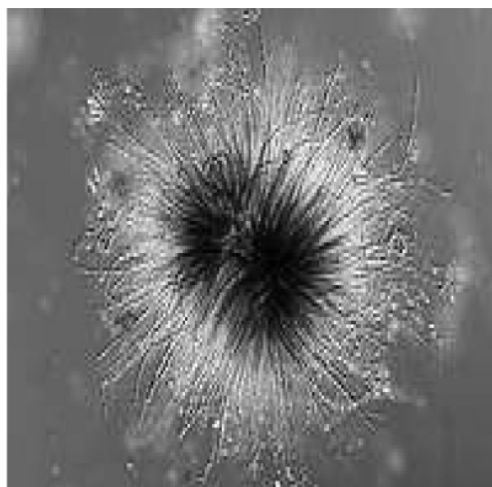


Figure 5: Members of Nostocales. *Anabaena* sp. (A), *Nostoc* sp. (B), *Gloeotrichia* sp. (C), *Scytonema* sp. (D) and *Nodularia spumigena* (E). Magnification bar represents 5 μm (C), and 10 μm (A, B, D and E). Pictures A to D courtesy G. L. Tiwari, Department of Botany, University of Allahabad, Allahabad-211002, India. Picture E courtesy Christina Esplund, Linnaeus University, School of Natural Sciences, Department of Marine Ecology, SE-391 82 Kalmar, Sweden.

Some distinctive features of the classification of Hoffmann *et al.* (2005) are: (i) Coccoid species of *Merismopedia* have been separated on the basis of cell size (small-celled *Merismopedias* included in Synechococcales of the first sub-class Synechococcineae and large-celled *Merismopedias* included in Chroococcales of the second sub-class Oscillatorineae). (ii) The members of heterocystous, true-branched members have been separated into three families of Nostocales on the basis of type of branching. Members with Y-shaped branching have been placed in Symphonemataceae while those with T-shaped branching pattern are included in Hapalosiphonaceae. *Stigonema* which exhibits multiserial branching was placed in Stigonemataceae. However, Komárek (2005) pointed out that (i) molecular (phylogenetic) data should be accepted as the basic criterion for the classification; (ii)



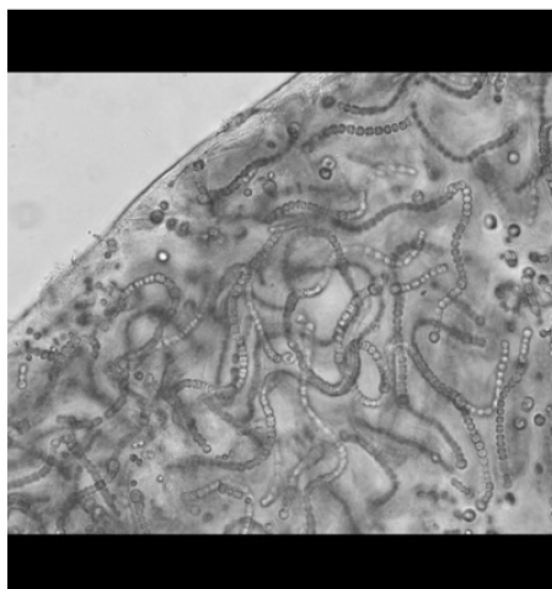
(A)



(B)



(C)



(D)

Figure 6: Members of Nostocales. A colony of *Gloeotrichia echinulata* (A), *Anabaena spiroides* (B), *Cylandrospermum* sp. with terminal heterocyst and sub-terminal akinete (C) and a portion of colony of *Nostoc commune* magnified (D). Magnification of pictures (A), (B) $\times 200$; (C) $10\ \mu\text{m}$ and pictures (A) and (B) in Nomarski contrast. Pictures (A) and (B) courtesy P. Znachor, Laboratory of Phytoplankton Ecology, Institute of Hydrobiology, Biology Centre ASCR, Na Sádkách, 37005 České Budějovice, Czech Republic. www.FytoPlankton.cz. Picture (C) courtesy Ralf Wagner (Dusseldorf), Mark Schneegurt (Wichita State University) and Cyanosite (www-cyanosite.bio.purdue.edu). Picture (D) courtesy Mark T. Aubel, GreenWater Laboratories/ CyanoLab, 205, Zeagler Drive, Suite 302, Palatka, Florida 32177, USA. (http://www.greenwaterlab.com/photo_algal.htm).

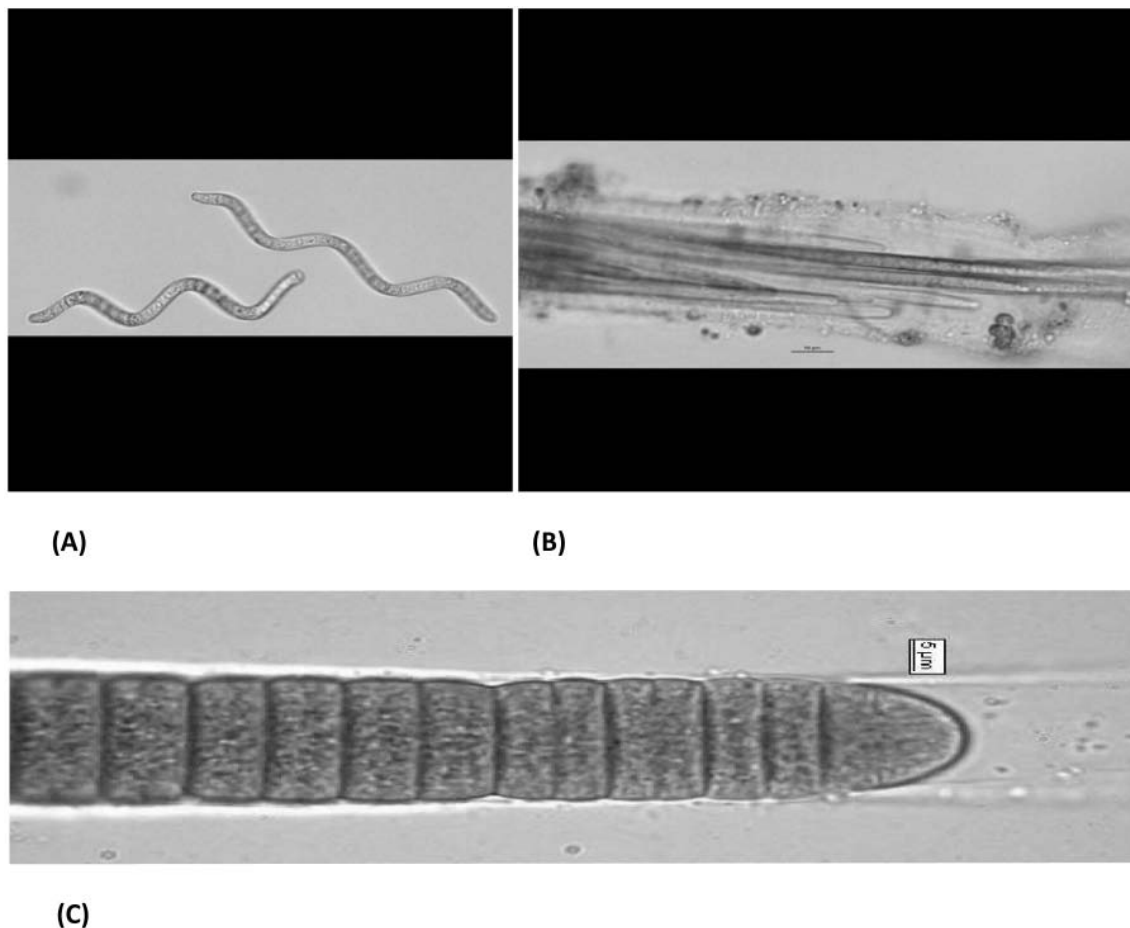


Figure 7: Members of Nostocales. Trichomes of *Arthrospira maxima* (A), *Microcoleus lacustris* (B) and *Porphyrosiphon* sp. (C). Magnification bar in picture (B) 10 µm and picture (C) 5 µm. Pictures (A) and (B) courtesy Mark T. Auel, GreenWater Laboratories/CyanoLab, 205, Zeagler Drive, Suite 302, Palatka, Florida 32177, USA. (http://www.greenwaterlab.com/photo_algal.htm). Picture (C) courtesy G. L. Tiwari, Department of Botany, University of Allahabad, Allahabad-211002, India.

numerous clusters identified on the basis of 16S rRNA sequencing are more or less congruent with traditional taxonomic assignments. In this connection mention may be made of Oscillatorian genera *Planktothrix*, *Tychonema*, *Microcoleus*, *Trichodesmium*, *Arthrospira* and *Spirulina*. These are distinguishable on the basis of morphological features as well as their 16S rRNA sequence divergence is near 95% as suggested for distinguishing bacterial genera (Wayne *et al.*, 1987; Stackebrandt and Goebel, 1994). Similarly, in heterocystous genera *Cylindrospermum*, *Cylindrospermopsis* and *Anabaenopsis* are distinct morphologically and on molecular phylogeny.

Based on the recommendations of the subcommittee on Phototrophic Bacteria of the International Committee on Systematic Bacteriology (ICSB) of the International Association of Microbiological Societies (IAMS), the cyanobacteria have been included under the 1st Division followed by the bacteria in the 11th division in the eighth edition of Bergey's Manual of Determinative Bacteriology (Buchanan and Gibbons, 1974). However, looking into the advances made in the physiology, biochemistry

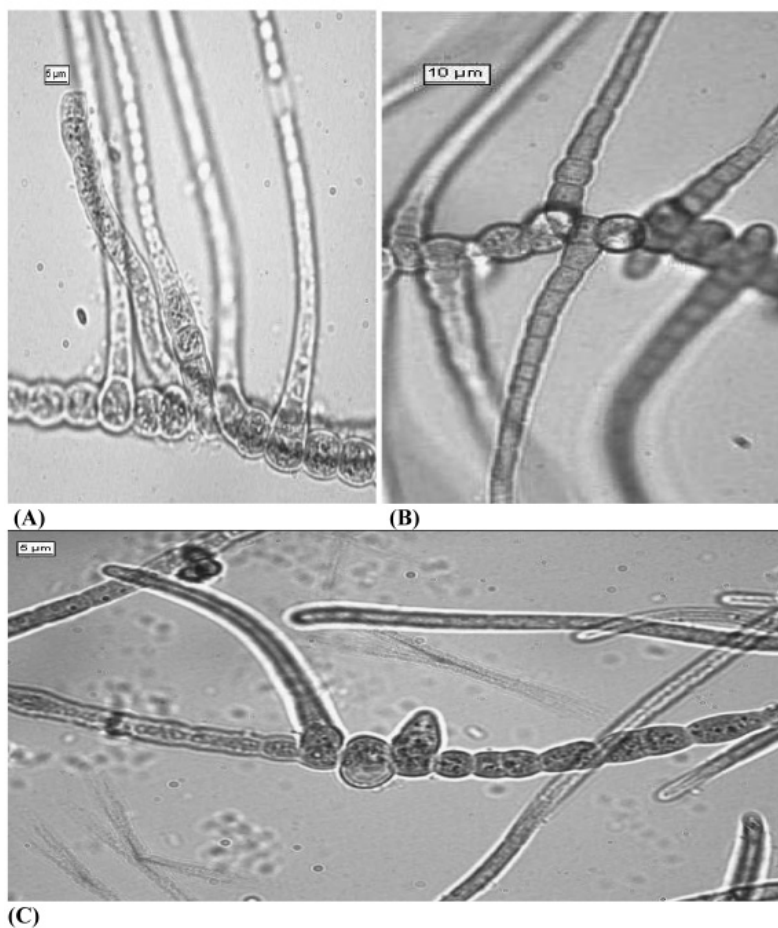


Figure 8: Members of Stigonematales. *Fischerella* sp. (A), *Hapalosiphon* sp. (B), *Westiellopsis* sp. (C), Magnification bar represents 5 µm (A and C) and 10 µm (B). Pictures courtesy G. L. Tiwari, Department of Botany, University of Allahabad, Allahabad-211002, India.

and genetic characterization of cyanobacteria based on pure culture techniques, Stanier *et al.* (1978) proposed the inclusion of cyanobacteria under the provisions of International Code of Nomenclature of Bacteria. In doing so, they emphasized that properties common to and distinctive to all bacteria may be extended to cyanobacteria. Accordingly, in bacterial taxonomy (Rule 18a) the type species and (through type species) genus is represented by living cultures of a strain so designated. They also cited Bacteriological Code of a Rule (18h) that permits the replacement of cultures by a description, a preserved specimen or an illustration of strains giving them the status of holotypes as has been permitted in case of myxobacteria. However, this provision seems to have been withdrawn with effect from November, 2000 (De Vos and Trüper, 2000). Rippka *et al.* (1979) suggested a classification based on bacteriological code and divided the cyanobacteria into five sections. In Section I and Section II members belonging to the orders Chroococcales; Chamaesiphonales and Pleurocapsales as suggested in the Botanical Code have been redistributed. Section III entirely consists of non-heterocystous filamentous cyanobacteria and Sections IV and V comprise heterocystous,

unbranched and branched representatives, respectively. The following is the classification scheme presented by Rippka *et al.* (1979) for cyanobacteria.

Section I (Unicellular): This section consists of unicellular cyanobacteria that reproduce by binary fission or by budding and separated into three groups on the basis of baeocyte (a new term coined to represent the erstwhile endospores or exospores) formation. The first group comprises of *Synechococcus* Nageli 1849 (thylakoids present; sheath absent); *Gloeotheca* Nageli 1849 (thylakoids present; sheath present) and *Gloeobacter* Rippka, Waterbury & Cohen-Bazire 1974 (thylakoids absent; sheath absent) that form baeocytes by binary transverse division. The second group comprises unicellular members that produce baeocytes in two or three successive planes and represented by *Synechocystis* Sauvageau 1892 (thylakoids present; sheath absent) and *Gloeocapsa* Kützinger 1843 (thylakoids present; sheath present). The third group is represented by *Chamaesiphon* Braun & Grunow 1895 emend Geitler 1925 that reproduces by budding from one pole of the ovoidal cell.

Section II (Unicellular): This section is divided into three groups. The first group is represented by members that are unicellular and reproduce by the formation of baeocytes by multiple fission and the baeocytes may be motile or immotile. Examples are *Dermocarpa* Crouan & Crouan 1858 (motile baeocytes) and *Xenococcus* Thuret 1880 (immotile baeocytes). The members of the second group reproduce both by binary fission and multiple fission and represented by *Dermocarpella* Lemmermann 1907; *Myxosarcina* Printz 1921; *Chroococcidiopsis* Geitler 1933. *Pleurocapsa*-group with binary fission yields irregular cellular aggregates and forms pseudofilamentous structures with the formation of motile baeocytes by multiple fission.

Section III (Filamentous): Filamentous non-heterocystous cyanobacteria that divide in only one plane with helical (*Spirulina* Turpin 1827) or straight trichomes (*Oscillatoria* Vaucher 1803) are included here. The other non-heterocystous cyanobacteria (*Lyngbya*, *Phormidium* and *Plectonema*) have been merged into LPP group A: *Pseudoanabaena* Lauterborn 1915 and LPP group B.

Section IV (Filamentous): This section consists of filamentous cyanobacteria that form heterocysts and divide in only one plane. On the basis of hormogone formation, cell size and shape two groups are recognized. The members of the first group reproduce by random trichome breakage to form hormogones that are indistinguishable in cell size and shape from main filaments and some form akinetes. *Anabaena* Bory de St. Vincent 1822, *Nodularia* Mertens 1822 and *Cylindrospermum* Kützinger 1843 are the representatives. The members of the second group form hormogones with rapid gliding motility and possess smaller cells with gas vacuoles. *Nostoc* Vaucher 1803, *Scytonema* Agardh 1824 and *Calothrix* Agardh 1824 are the genera recognized.

Section V (Filamentous): These are represented by heterocystous, branched forms that divide in more than one plane, form hormogones and some differentiate akinetes. *Chlorogloeopsis* Mitra & Pandey 1966 and *Fischerella* Gomont 1895 are the representatives.

The scheme of Rippka *et al.* (1979) was adopted and modified in Bergey's Manual of Systematic Bacteriology (Boone and Castenholz, 2001). The cyanobacteria constitute a monophyletic group within Eubacteria and are closely related to purple bacteria and gram-positive bacteria. At present, the phylum cyanobacteria includes two groups of oxygenic photosynthetic bacteria i.e. chlorophyll-*b/a* containing Prochlorales (Prochlorophyta), and cyanobacteria (Castenholz, 2001). In this Manual five Subsections ("Orders") have been recognized. Subsection I consists of unicellular or non-filamentous aggregates of cells (or in other words colonial forms) that reproduce by binary fission in one, two or three planes, symmetric or asymmetric or by budding (corresponding to the Order Chroococcales

under ICBN and Section I of Rippka *et al.*, 1979). Subsection I though includes *Chroococcus*, *Cyanobacterium*, *Cyanobium*, *Dactylococcopsis*, *Microcystis* but differs from traditional Chroococcales by the inclusion of the two Prochlorophytes, *Prochloron* and *Prochlorococcus* and *Chamaesiphon* that reproduces by budding. Subsection II comprises unicellular or colonial forms that reproduce by internal multiple fissions with production of daughter cells smaller than the parent or by multiple fission plus binary fission (corresponds to the orders Chamaesiphonales and Pleurocapsales under ICBN and Section II of Rippka *et al.*, 1979). Subsection III is composed of filamentous forms where the trichomes do not possess differentiated cells like heterocysts or akinetes (corresponds to the non-heterocystous families under the order Nostocales under ICBN and Section III of Rippka *et al.*, 1979). Subsection IV characteristically possesses forms with trichomes differentiating into heterocysts when the concentrations of nitrate or ammonium in the medium is low and some differentiate akinetes as well (corresponds to heterocystous Nostocales under ICBN and Section IV of Rippka *et al.*, 1979). Subsection V consists of true branching representatives that develop multiserial trichomes and are heterocystous and some produce akinetes (corresponds to the order Stigonematales under ICBN and Section V of Rippka *et al.*, 1979). Gibbons and Murray (1978) suggested that the cyanobacteria be treated under the order 'Cyanobacteriales' and integrated with photobacteria. The name of the order was not based on a designated name of genus or species. Although a special request was made by these workers to the Judicial Commission of International Committee on Systematic Bacteriology, their proposal was not accepted (Holt, 1979). In order to pave the way for the creation of this order under Bacteriological Code, Rippka and Cohen-Bazire (1983) created two genera *Cyanobium* and *Cyanobacterium*. The type species of the genus *Cyanobacterium* as *Cyanobacterium stanieri* (strain PCC 7202; ATCC 29140; in honour of late R. Y. Stanier) should fulfill the condition for the creation of the order Cyanobacteriales under the Bacteriological Code. One of the intriguing aspects of this classification is the recognition of 'form genera' a term that has no standing either under ICBN or Bacteriological Code (Oren, 2004). The concept of 'form species' has been questioned by Whitton and Potts (2000). The number of genera validly published under Bacteriological Code is only six and 13 species names have been proposed in the validation lists published by International Journal of Systematic and Evolutionary Microbiology or International Journal of Systematic Bacteriology.

Cavalier-Smith (2002) classified all bacteria into a single Kingdom, i.e. Kingdom Bacteria. The ancestors for the development of cyanobacteria have been identified as Negibacteria (Sub-Kingdom I) in which two Infrakingdoms Eobacteria (Infrakingdom I) and Glycobacteria (Infrakingdom II) have been recognized. Cyanobacteria are included in Division I that has been divided into two Sub-divisions, Gloeobacteria (Sub-division I; with the only known genus *Gloeobacter* having phycobilisomes but without thylakoids) and Phycobacteria (Sub-division II; consisting of all the traditional blue-green algae and Prochlorophytes). He formally validated all the five traditional cyanobacterial orders (valid under ICBN) under the Bacteriological Code under two Classes.

Class I: Chroobacteria: Based on the genus *Chroococcus*; unicellular, palmelloid, colonial or with filaments lacking heterocysts.

Order 1: Chroococcales

Order 2: Pleurocapsales: Colonial or filamentous, reproducing by intramural multiple fission to yield small unicellular dispersal stages.

Order 3: Oscillatoriales: Unbranched linear filaments without heterocysts, cells typically shorter than broad.

Class II: Hormogoneae (ex. Thuret 1875)

Order 1: Nostocales: *Nostoc*, filaments that multiply vegetatively by hormogonia usually with heterocysts, unbranched.

Order 2: Stigonematales: *Stigonema*, branched, heterocystous forms.

II. PHYLOGENY

Phylogenetic relationships tell us the manner in which the different groups of organisms have evolved during the course of time. In case of eukaryotes (both animals and plants), macromorphological features (organismal biology) form the main basis for drawing phylogenetic relationships. In case of prokaryotes, the range of morphological features being very limited, a number of other corollary features have been taken into consideration. Along with morphological features, immunological, physiological, biochemical, ecological as well as genetic features have been taken as the supporting taxonomic features to identify bacteria and draw their phylogeny. This has given rise to a polyphasic approach to taxonomy. In this connection, a single gene whose sequence is highly conserved and at the same time shows variable sequences that could form the basis for identification can be selected. The first choice fell on 16S rRNA gene. The projection of this gene as molecular marker for drawing phylogenetic relationships has revolutionized thinking in biological world with the culmination of the classification of living organisms into bacterial, archaeobacterial and eukaryotic domains (Woese *et al.*, 1990). This triggered a large number of studies all world over and generated a wealth of knowledge. These studies have clearly pointed out that the sequencing of 16S rRNA gene falls short of differentiating bacteria up to or below the level of species. It turned out that the rRNA operon that consists of internally transcribed sequences (ITS) between 16S and 23S rRNA could well serve as a good parameter. This has no doubt helped in the identification of bacteria up to strain level and the resolving power of this ITS is found to be greater than simply sequencing of 16S rRNA. Alternative searches for other ideal genes suited for this purpose resulted in the identification of some housekeeping genes such as RNA polymerase gene, cell division genes and genes involved in DNA repair. Taking 16S rRNA phylogeny as the basis, comparisons have been made between other gene markers selected and the resulting phylogenies. This gave rise to the concept of multi-locus sequence typing (MLST). Another most promising, reliable but very expensive approach is whole genome sequencing of bacteria and comparisons between the bacterial species in question. The studies on genomics have converged with phylogeny resulting in an interesting area known as Phylogenomics (Eisen, 1998; Eisen and Fraser, 2003). All these developments are detailed below.

1) 16S rRNA gene

The 16S rRNA gene has all the characteristics for a phylogenetic marker gene because of its universal distribution in prokaryotes, functional consistency, the presence of variable and conserved regions and high information content (Woese, 1987; Ludwig and Klenk, 2001; Figs. 9 and 10). Other attributes of 16S rRNA gene are (i) its suitable length of about 1500 bp, (ii) the presence of long highly conserved regions useful for measuring distant phylogenetic relationships, (iii) the presence of sufficient variable regions to measure close relationships, (iv) not prone for rapid sequence change and (v) not liable for getting transferred from one organism to another through lateral gene transfer (LGT). Woese (1987) considered it an excellent molecular chronometer for finding out evolutionary relationships among all living organisms. On the basis of 16S rRNA gene sequences, Woese *et al.* (1990) proposed a three

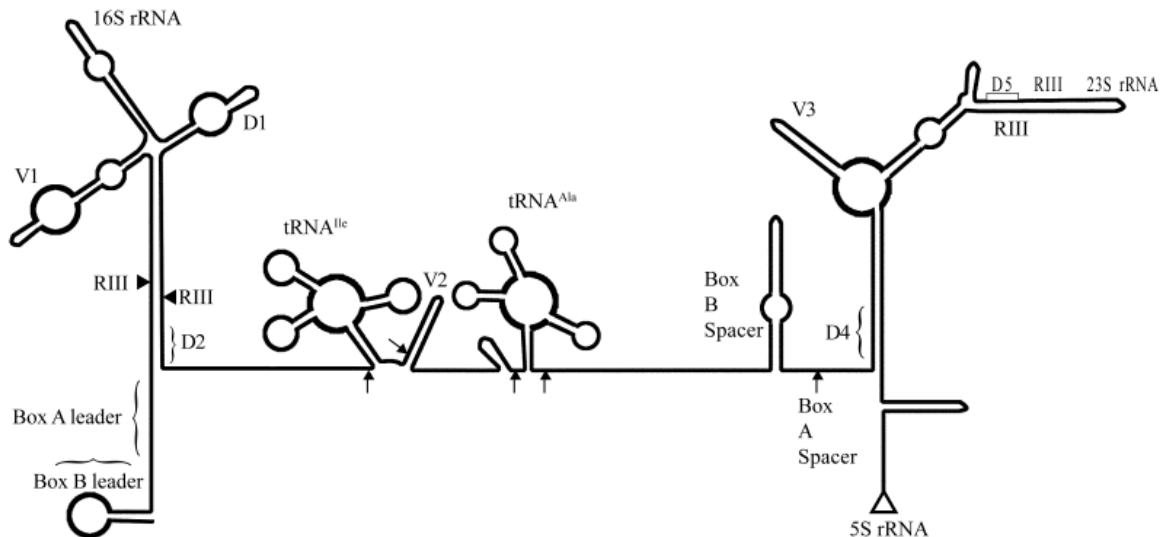


Figure 9: Diagrammatic representation (not drawn to scale) of rRNA operon of *E. coli*. D1, D2, D4 and D5 represent conserved domains and V1, V2 and V3 represent variable regions. Based on the molecular structure as in Iltman *et al.* (2000).

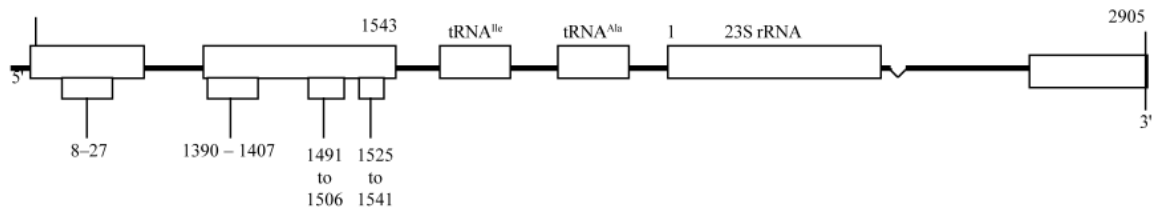


Figure 10: Line drawing (not drawn to scale) of rRNA operon of *E. coli* showing specific regions of 16S rRNA that are generally amplified in the identification of prokaryotes. There are six other regions in 23S rRNA also (not shown) utilized for this purpose. Modified from Gürtler and Stanisch (1996).

domain classification consisting of Bacteria, Archaea and Eukarya (Fig. 11). Studies on this molecule have generated a huge public data base (RDP II: <http://rdp.cme.msu.edu/> containing 481,650 16S rRNAs as on 13th February, 2008). It is generally agreed that a 16S rDNA sequence similarity of 96–97% and DNA:DNA hybridization value of 70% relative binding (RB) with ΔT_m 5°C represent lower boundaries for the distinguishing bacterial species (Wayne *et al.*, 1987). Fox *et al.* (1992) reported that three psychrophilic strains of *Bacillus* (*B. globisporus* W25^T Type strain; *B. psychrophilus* W16A and W5) that are phenotypically very similar exhibited 99.5% 16S rRNA gene sequence similarity but differed from each other on the basis of DNA:DNA hybridization studies. They concluded that identity of 16S rRNA sequences does not constitute a sufficient criterion to guarantee species identity. A number of proposals have been made for altering the lower limits for the delineation of a species in bacteria. An RB value of 50% at a ΔT_m 7°C has been suggested by Rosselló-Mora and Amann (2001) for distinguishing species because even if 16S rDNA sequence similarity was as high as 98–99% the total DNA homology was as low as 10–40% RB. Similarly, Keswani and Whitman (2001) observed that the relationship between RB and 16S rDNA sequence similarity greatly varied within the same subphylum. In view of these, it appears that there is a need to alter the upper and lower limits of RB values for species delimitation in prokaryotes.

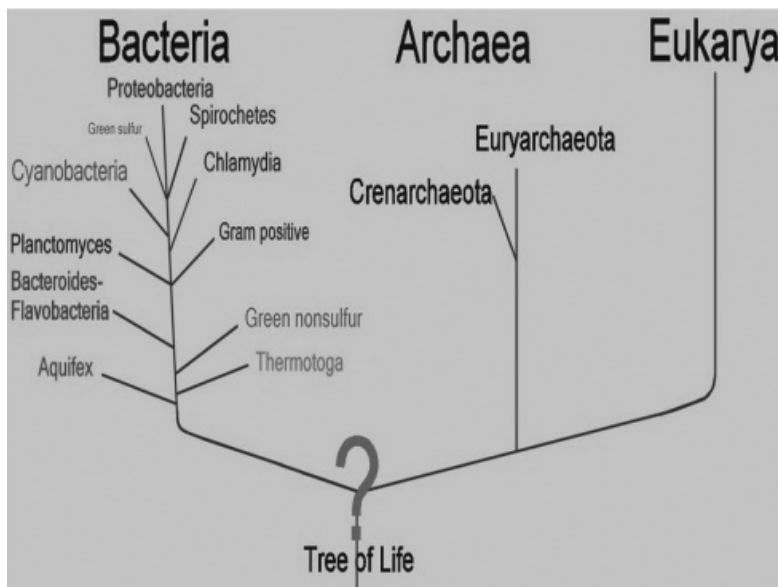


Figure 11: Three domain classification of living world based on 16S rRNA sequencing.

The 16S rRNA gene sequences are easy to align that allow comparison between strains. This is a crucial step in phylogenetic analysis (Swofford *et al.*, 1996). In alignment, the sequences are arranged in such a manner by inserting gaps so that the homologous positions of sequences are placed in the same columns of the data matrix. A number of computer programmes have been used for aligning the sequences, e.g. GenBank or EBI (European Bioinformatics Institute), Ribosomal Data Base Project (RDP) and Antwerpen Projects. Further, a variety of individual software tools for sequence editing, alignment and phylogenetic analyses are available from different software packages such as phylogeny inference package (PHYLIP; Felsenstein, 1989), Maximum likelihood (ML method; FastDNAm1; Olsen *et al.*, 1994); molecular phylogenetics based on Maximum-likelihood (Molphy-Version 2.3), multiple sequence alignment (ClustalW; Thompson *et al.*, 1994; Chenna *et al.*, 2003) and ARB software (Ludwig *et al.*, 2004; accessible at <http://www.arb-home.de>). Although ARB software initially was designed for rRNA data, it can now be used for any nucleic acid or amino acid sequence as well. This software is helpful in aligning the sequences through primary structure data that contains processed aligned sequences for comparison. It can be linked via local or worldwide networks. Tools for data import and export, primary and secondary structure editing, specific hybridization probe design are the additional features of the ARB software. ClustalW and ClustalX version 2.0 multiple sequence alignment programmes have been completely rewritten in C++ and made available at <http://www.ebi.ac.uk/tools/clustalw2> by Larkin *et al.* (2007).

At this stage, it is required to know the definitions of gene terminology used while drawing molecular phylogenetic relationships: (i) homologues are those genes that have descended from a common ancestor (e.g. all globin genes); (ii) orthologues are those homologous genes that have diverged from each other after speciation events (e.g. human β - and chimp β -globin); (iii) paralogues are those homologous genes that have diverged from each other after gene duplication events (e.g. β - and gama-globin) and (iv) xenologs are those homologous genes that have diverged from each other after LGT events (e.g. antibiotic resistance genes in bacteria). Positional homology is a specific amino acid or nucleotide positions in different genes. The methods of predicting gene function when

homologues have multiple functions are to identify highest hit and top hits. The uncharacterized gene is assigned the function of the gene that is identified as the highest hit by a similarity search programme. Top 10+ hits are identified for the uncharacterized gene. Depending on the degree of consensus of the top hits, the query sequence is assigned a specific function.

Evolutionary trends are represented in the form of a phylogenetic tree. It is a graphical representation of the evolutionary history of genes or species. The branching pattern of a tree (topology) displays the evolutionary relationships of the strains. A tree consists of nodes and edges. The nodes correspond to organisms and the edges show their relationships. The terminal nodes possess only one linking edge and correspond to organisms for which we have data. These are commonly designated as operational taxonomic units (OTUs). Internal nodes possess three linking edges and correspond to hypothetical ancestor of one set of organisms. One unique internal node with only two edges represents the root of the tree, the common ancestor to all taxa.

The phylogenetic trees may be represented as rooted or unrooted. Rooted or unrooted trees are identical except that in the former nodes are present while in the latter nodes are absent but possess only two connecting edges (Fig. 12). All proposed tree-building methods fall into two general classes: algorithmic and optimal criteria approaches. In the former, a unique tree can be built by a series of steps while in the latter all possible trees are examined and one best meeting the certain criteria is chosen. In the algorithmic approach, the algorithm plays a fundamental role but in optimal criteria approach the algorithm simply is a tool to evaluate the criteria. Algorithmic approaches are known as distance methods because they compute a tree via a distance matrix composed of the distances between each pair of sequences. A distance based algorithm is basically a procedure for building a tree based on the matrix. If the outputted tree is to be additive it must obey four basic rules, i.e. (i) all distances are positive; (ii) a distance between two points can be zero only when the two points are actually the same; (iii) the distances are symmetrical and (iv) there are no shortcuts in the tree, i.e. the distance between a-c cannot be longer than the sum distances of a-b and b-c. In addition, a tree point condition is applied that is distance a-b cannot be larger than their distance to a third point (the maximum distances a-c and b-c). Unweighted Pair Group Method (UPGMA) is an ultrametric tree-building algorithm that follows all the rules mentioned earlier. UPGMA proceeds by inferring one ancestral sequence per step. In the first round UPGMA selects the least distant pair of sequences (or one of them), summarizes their distance as the first branches of a new tree and recalculates the entire matrix with the pair as one entity (taking the mean distances). After N-1 steps (where N is the number of sequences) the matrix is reduced to just one element. The last inferred ancestor is taken as the root of the tree. Distance methods such as neighbor joining (NJ) use pair-wise distances (i.e. the number of base differences between two sequences), calculated from aligned sequences and usually

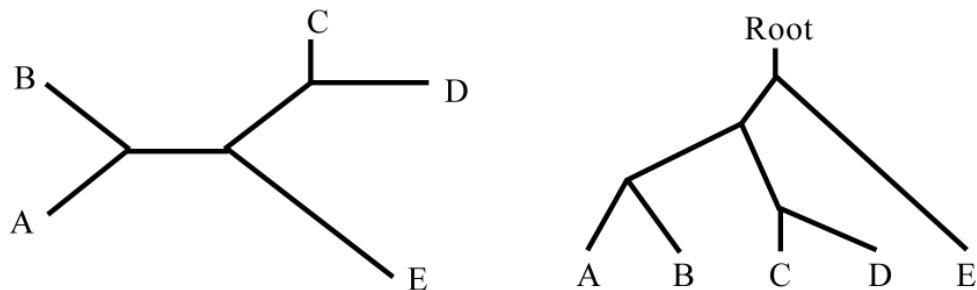


Figure 12: Representation of unrooted (left) and rooted (right) phylogenetic trees.

corrected to evolutionary distances within a substitution mode (Saitou and Nei, 1987). The sequences with the shortest distances are clustered together in a tree, where the tree length is optimized to correspond to the distance matrix. The root is not specified by a NJ tree. It is very common to identify the root by adding a sequence to the set that is known to be more different from all the others that is known as an out group. The position of the out group on the tree indicates the root. For example, in the case of the human mitochondria, a chimpanzee outgroup was used to identify the root.

There are two methods under optimal criteria approach. These are maximum parsimony (MP) and maximum likelihood (ML) methods (Nei and Kumar, 2000; Ludwig and Klenk, 2001). The MP method uses the actual sequence data instead of distances and searches for the tree(s) with minimum length, i.e. topology of the tree can be explained with a minimum number of transformations from one character state to another. A number of possible trees are compared and each is given a score that is a reflection of minimum number of character changes (e.g. amino acid substitutions) that would be required over evolutionary time to fit the sequences in that tree. Comparing the number of inferred mutations for each possible tree, we define an informative site as one that favours one of the possible trees in terms of fewer mutations. The optimal tree is considered to be the one requiring the fewest changes, the most parsimonious tree.

ML method is similar to MP method in that possible trees are compared and given a score. The score is based on how likely the given sequences would have evolved in a particular tree given a model of amino acid or nucleotide substitution probabilities. It estimates the likelihood for tree topology that could have resulted in the sequence alignment under the given model of evolution and searches for the tree with maximum likelihood (Swofford *et al.*, 1996; Nei and Kumar, 2000). Bootstrapping is a statistical method in which resamplings are made within the original multiple sequence aligned and new data sets are made. Starting with the multiple sequence alignment it builds a random multiple sequence alignment by sampling with replacement the different sites of the original multiple alignment. For a large number, say 10,000, of such pseudo multiple sequence alignments a tree is built by the same method used to build the original trees. Each node of the tree can be given a bootstrap percentage indicating how frequently those species joined by that node group together in different trees. It is particularly convenient because it does not require anything more than the actual data used to build the tree. It can also be used in conjunction with any tree-building method. Based upon the 10,000 trees, bootstrapping can be used to annotate the internal branches of the original tree. For each internal branch, we count how many times the same particular “split” is found among the 10,000 trees. The higher this number the more one is confident in the robustness of the split.

2) Molecular techniques based on 16S rRNA gene

A number of analytical methods are now available for measuring the variations in the sequences of 16S rDNA. Pure cultures of microorganisms whose identification has been made on a polyphasic approach (that is based on morphological, biochemical, physiological, phenotypic and chemotaxonomic criteria) can be subjected to 16S rRNA gene sequence analysis and phylogenetic relationships can be drawn by any one of the methods described above. During recent years, ecological criteria are given equal importance with molecular markers in the identification and characterization of strains of bacteria into ecotypes (Whitaker *et al.*, 2003; Whitaker, 2006; Martiny *et al.*, 2006; Staley, 1999, 2006; Cohan, 2006; Fraser *et al.*, 2008). To investigate the prokaryotic diversity of a given ecosystem, culture-independent approach known as metagenomic analysis has been developed. According to Whitman *et al.* (1998) the prokaryotic diversity assumes greater significance as their cellular production rate is estimated to be 1.7×10^{30} cells per year and their carbon content equals

to nearly 60–100% of that present in plants. Furthermore, their contribution is highest in the open oceans. Thus the newly emerging metagenomic analysis has to its credit more than 100 projects in the GOLD web site, Genomes OnLine Database [February, 2008; <http://www.Genomesonline.org/gold> (gi)]. Of these, 31 projects have already been completed. By now, nearly 120,000 sequences are deposited in databases such as RDP. Mention may be made of four large environmental sequencing projects that have been completed from acid mine drainage (Tyson *et al.*, 2004), Sargasso Sea (Venter *et al.*, 2004), farm soil (Tringe *et al.*, 2005) and whale falls (Tringe *et al.*, 2005). In terms of minimum number of species Sargasso Sea is at first position (with 1000 species) whereas in terms of estimated total number of species farm soil occupied the first place with >3000 species. Likewise, in terms of total number of ORFs annotated Sargasso Sea showed maximum (>1000,000) followed by farm soil (>180,000) (Foerstner *et al.*, 2006). There are seven techniques identified for analysis of 16S rRNA gene. These are as follows.

(i) Oligonucleotide cataloguing: This is one of the earliest techniques used to identify bacteria. The 16S rRNAs from individual bacteria is digested with ribonuclease T1 (which cleaves specifically at G residues) and produces short oligonucleotides of lengths up to 20 or so. A collection of these from a given rRNA consists of oligonucleotide catalogue (Fox *et al.*, 1977). A specific pattern characteristic of a given species is obtained that enables one to arrange bacteria into phylogenetic groupings. The data are represented in terms of binary association coefficients (called as S_{AB} values) defined as the ratio of twice the sum of bases in oligonucleotides in two catalogues. Because of its failure to identify bacteria beyond their phyla and branching orders or their subdivisions, sequencing approach received more attention subsequently (Woese, 1987).

ii) Sequencing of 16S rRNA gene: Total community DNA or DNA extracted from identified cultures is used as a template for polymerase chain reaction (PCR) amplification of 16S rRNA genes with universal or domain specific primers. A clone library is constructed for genes encoding rRNA (rDNAs) and is screened for finding out the sequence differences and phylogenetic relationships are drawn. By applying this method one can assess the richness and evenness of a community qualitatively based on the number of unique clones and the relative frequencies of each “ribotype”. Schmidt *et al.* (1991) described a technique for analysis of marine picoplankton community by 16S rRNA gene cloning and sequencing bypassing culture of the organisms. In this method, natural picoplankton populations are collected and filtered by tangential flow filtration. The collected biomass is subjected to DNA extraction and DNA is purified by CsCl gradient centrifugation. The DNA obtained is fragmented, size-fractionated and cloned into bacteriophage lambda. Out of 3.2×10^4 recombinant phages, 38 clones of lambda phage containing the 16S rDNA were screened by hybridization with “mixed kingdom” 16S rRNA probes. Ribosomal DNA clones are then sorted, PCR amplified with r-DNA specific primers. Single strand rDNA clones were subjected to sequencing to obtain nucleotide pattern. Then phylogenetic characterization of the constituents of the population revealed the identity of 4 cyanobacterial, 11 proteobacterial and 1 eukaryote 16S rDNA sequences. An alternative method for 16S rDNA sequencing that is quite faster and cheaper is Random Sequence Reads (RSRs). RSRs are quite suitable for comparative study of the biodiversity of a metagenomic library. In this method, the sequence analysis of oligonucleotide frequencies represented in the genomes permits the identification of different species (Karlin and Burge, 1995; Abe *et al.*, 2003). Manichanh *et al.* (2008) compared RSR method against 16S rDNA sequencing for estimating the biodiversity of a metagenomic library. The sequences of the oligonucleotides are compared with a database of prokaryotic sequences (GenBank-prok) using BLASTN. They applied this local alignment programme to find out the closest relative for each of the RSRs out of a total of 516,770 entries. By

taking into account the top Blast hit, they identified the species to which the sequence belongs and performed the taxonomic assignment. Pyrosequencing is another technique that is dependent on the characterization of PCR products of 16S rDNA. This is a cheap, labour saving method that does not involve cloning of the gene. The original instrument known as GS20 Instrument that has been fabricated by Margulies *et al.* (2005) sequences approximately 100 bases. The current GS FLX platform can sequence 250 bases and the next generation GS XLR instrument is expected to sequence nearly 400 bases. Liu *et al.* (2008) performed accurate taxonomic assignments from the 16S rRNA gene sequences produced by highly parallel pyrosequencers.

iii) 16S rRNA-23S rRNA operon copy number and the internally transcribed spacer (ITS) sequences: Bacterial rRNA genes are commonly present in a single operon in the order of 16S rRNA-23S rRNA-5S rRNA each of which is separated by one ITS region (Srivastava and Schlessinger, 1990). One or two tRNA genes (either tRNA^{Glu}/tRNA^{Ala} or both tRNA^{Ala} and tRNA^{Ile}) are often present in the 16S rRNA-23S rRNA ITS region. However, in certain bacterial species like *Thermus thermophilus* (Srivastava and Schlessinger, 1990), *Leptospira interrogans* (Fukunaga and Mifuchi, 1989), *Borrelia* spp. (Ojaimi *et al.*, 1994) and *Wobachia pipientis* (Bensaadi-Merchermeek *et al.*, 1995) the rRNA genes are separated into two distinct 16S rRNA and 23S rRNA operons. In case of bacteria, great variation in between the number of ITS regions and alleles of the rRNA operon has been found. For example, in *Escherichia coli* there are 7 copies of operons coding for the three rRNAs (Morgan *et al.*, 1977) whereas in *Bacillus subtilis* (Loughney *et al.*, 1982) and *Clostridium perfringens* (Garnier *et al.*, 1991) 10 copies each of the operons coding for the three rRNAs are present. On the other hand, one copy of the operon is present in *Mycobacterium* sp. (Bercovier *et al.*, 1986) whereas one to two copies of the operon may be present in *Mycoplasma* (Amikam *et al.*, 1984). Moreover, greater heterogeneity in these multiple copies has also been observed. In *E. coli* where these copies are named as *rrnA*, *rrnB*, *rrnC*, *rrnD*, *rrnE*, *rrnG* *rrnH*, the 16S rRNA-23S rRNA ITS region in the operons *rrnB*, *rrnC*, *rrnE* and *rrnG* contains a gene coding for tRNA^{glu-2} whereas operons *rrnA*, *rrnD* and *rrnH* have genes for tRNA^{Ile-1} and tRNA^{Ala-1B} (Antón *et al.*, 1998). However, majority of gram-positive bacterial species studied (15 out of 19) have no tRNA genes at all in the ITS region (Gürtler and Stanisich, 1996). This shows that there is a great variation in the number, length and composition of the 16S-23S rDNA spacer regions of diverse range of eubacteria and archaeobacteria. As a part of Human Microbiome Project (accessible at <http://nihroadmap.nih.gov/hmp>), the diversity of 16S rRNA genes in 883 prokaryotic genomes (including 13 from cyanobacteria) revealed 568 unique sequences. Of these, 425 species showed 2 to 15 copies of rRNA genes per genome. There is every possibility for taxonomic mis-classification, based exclusively on 16S rRNA, of a number of species into more than one species as it had happened with seven bacterial species associated with human disease development (Pei *et al.*, 2010). The diversity of 23S rRNA genes in 184 prokaryotic species has been determined by Pei *et al.* (2009) who found multiple 23S rRNA genes in 113 genomes. Significantly, eight of the species exhibited intragenomic variation in the 23S rRNA gene sequences. Intervening sequences ranging in length from 9 to 1471 nucleotides were found in seven species. In case of *Anabaena* sp. strain PCC 7120 there are four 23S rRNA genes of which *rrnA* 23S is 4299-nucleotides long whereas the rest of the three each are 2828-nucleotides long, the difference in the lengths is due to the presence of 1471-nucleotides long intervening sequence that encodes a transposase. The second organism that has a transposase gene as an intervening sequence, within the 23S rRNA gene, is *Deinococcus radiodurans* (Pei *et al.*, 2009). Rastogi *et al.* (2009) constructed phylogenetic trees based on rRNA copy numbers and genome sizes in which colour codes given with increasing rRNA copy numbers and genome sizes can be correlated with the colour codes given on the phylogenetic

tree constructed with the 31 housekeeping genes from 578 bacterial genomes. This will be useful in determining microbial diversity and reduces chances for mis-identification due to the existence of variable rRNA copy numbers.

A number of cyanobacteria have been studied for the sequences of the 16S rRNA-23S rRNA ITS domain. Three types of ITS regions have been identified. The first type contains both tRNA^{Ile} and tRNA^{Ala} sequences. These are found in *Anabaena* sp. (Lu, 1999), *Arthrospira* PCC 7345 (Nelissen *et al.*, 1994), *Nostoc* sp. (Lu, 1999), *Synechococcus* PCC 6301 ("*Anacystis*", Tomioka and Sugiura, 1984), and *Trichodesmium* NIBB 1067 (Wilmutte *et al.*, 1994). The second type of ITS regions contain only tRNA^{Ile} found in 47 strains of *Microcystis* (Otsuka *et al.*, 1999), *Spirulina* PCC 6313 (Nelissen *et al.*, 1994) and the unicellular *Synechocystis* sp. strain PCC 6803 (Kaneko *et al.*, 1996). Kaneko *et al.* (1996) identified two rRNA operons both consisting of tRNA^{Ile} present in inverted repeats in *Synechocystis* sp. strain PCC 6803. The third type of ITS regions do not contain any tRNA as noted in *Nodularia* BCNO D9427 (Hayes and Barker, 1997). The 16S rRNA-23S rRNA ITS sequences of two other cyanobacteria *Mastigocladus* HTF strain PCC 7518 of uncertain identity and that of the cyanelle *Cyanophora paradoxa* have also been determined (Iteman *et al.*, 2000). There is a great size variation in ITS regions of cyanobacterial origin. They vary from 354 to 545 nucleotides with the exception of 287 nucleotides in the cyanelle *C. paradoxa*. The existence of multiple rRNA operons was for the first time reported in three species of *Anabaena* and one species of *Nostoc* (Nichols *et al.*, 1982). The existence of four *rrn* operons in *Anabaena* sp. strain PCC 7120 was reported by Ligon *et al.* (1991). Three PCR products have been generated from the 16S rRNA-23S rRNA ITS region of *Anabaena* sp. strain PCC 7120. Of these, two of them represented the true ITS regions while the third fragment was longer (with 512 nucleotides) and possessed tRNA^{Ile} and tRNA^{Ala} genes separated by a large stem-loop structure (Iteman *et al.*, 2000). Further, these workers identified highly conserved motifs important for folding and maturation of rRNA transcripts (homologous to bacterial antiterminators boxB-boxA) that can serve as potential targets of PCR primers and oligonucleotide probes for detection and identification of cyanobacteria. The 16S rRNA-23S rRNA ITS regions of *Anabaena* sp. strain PCC 7120, *Mastigocladus* HTF strain PCC 7518 and *C. paradoxa* contain tRNA^{Ile} and tRNA^{Ala}. Boyer *et al.* (2001) examined variability in the ITS regions among multiple rRNA operons in five species of cyanobacteria (*Scytonema hyalinum*, *Tolypothrix distorta*, *Calothrix parietina*, *Coelodesmium wrangelii* and a new genus designated by isolates SRS 6 and SRS 70). The ITS regions from these organisms transcribe two tRNA molecules tRNA^{Ile} and tRNA^{Ala}. So in this respect, these species belong to the first type of ITS region described above. However, *C. parietina* and *S. hyalinum* also contained ITS regions without tRNA. In addition, *S. hyalinum* contained two non-coding ITS regions that are identical in length but differed in their sequences. The species included in their study has wider representation taxonomically because three of the species belonged to three of the four families of Nostocales. Boyer *et al.* (2001) cautioned that although the potential of ITS region as a tool for studying molecular systematic and population genetics is great but the presence of multiple non-identical rRNA operons poses a problem, especially in sequence comparison and secondly when restriction digests of PCR products are analyzed. So as to enable investigators to align and compare the highly variable ITS region, D'Auria *et al.* (2006) created a software known as Word Count based (IWocS) system with 32,061,819 entries of which 482 sequences pertain to cyanobacterial ITS sequences. Of these, 204 sequences pertain to Chroococcales, 56 of Nostocales, 60 of Oscillatoriales, 67 of Prochlorales, 2 of Stigonematales and 93 unidentified/unknown sequences. This provides a novel tool for the use of ITS sequences in typing and identification of bacteria and cyanobacteria.

iv) Amplified rDNA restriction analysis (ARDRA): Ever since this method was discovered by Grimont and Grimont (1986) more than 2000 research papers have been published on 16S rRNA

gene restriction patterns leading to the establishment of 'ribotyping' as potential taxonomic tool for the enumeration of bacterial diversity. The molecular genetic basis of ribotyping has been elucidated (Bouchet *et al.*, 2008). This is considered to be a rapid method for comparisons of rDNAs (Laguerre *et al.*, 1994; Moyer *et al.*, 1994). It involves digestion of rDNAs (obtained by PCR amplification by using universal primers) with restriction enzymes that have 4-bp recognition sites. The restriction digests are analysed by agarose gels. For community analysis, the large number of fragments can be resolved by using polyacrylamide gels to produce community specific pattern (Martínez-Murcia *et al.*, 1995; Massol-Deya *et al.*, 1995). The disadvantage with this method is that it is of limited use for detecting specific phylogenetic groups or for estimating species richness or evenness.

A variation of the above method is to subject the whole genomic DNA for restriction analysis instead of a single gene as in ARDRA. This is termed as amplified fragment length polymorphisms (AFLPs). Naturally occurring DNA polymorphisms are basically due to point mutations or rearrangements (i.e. insertions and deletions) in the DNA. AFLP analysis is based on selective amplification of DNA restriction fragments (Vos *et al.*, 1995). Restriction enzyme digestion of genomic DNA is followed by PCR amplification and the products are subjected to separation by electrophoresis. This enables us to detect the presence or absence of such polymorphisms by the presence or absence of banding patterns. The variation in banding patterns may directly reflect the genetic relationships between the bacterial strains examined. So these banding patterns in other words represent genomic fingerprints allowing numerical analysis for characterization and identification. Genome-wide variations in the strains can be scanned by AFLP. Thus it will greatly help in the resolution of taxonomic problems which are otherwise problematic and answers for these are difficult to obtain through morphological features or by other molecular methods. The broad taxonomic applicability of this technique has been tested in case of bacteria (Huys *et al.*, 1996) and fungi (Majer *et al.*, 1996). The advantage of AFLP over other techniques is that multiple bands are derived from all over the genome. This prevents over interpretation or misinterpretation due to point mutations or single-locus recombination, which may affect other genotypic characteristics. The main disadvantage of AFLP markers is that alleles are not easily recognized (Majer *et al.*, 1998). Due to the inherent advantages of its utility, reproducibility and efficiency, the AFLP technique has been used to investigate cyanobacterial populations as well (Janssen *et al.*, 1996).

RAPD fingerprinting in conjunction with PCR has been used to identify microorganisms to the strain level (Welsh and McClelland, 1990). The sequences frequently used are short tandemly repeated repetitive sequences (STRR). These are of the nature of heptanucleotide sequences that are present nearly at the rate of 100 copies per genome of *Calothrix* sp. strain PCC 7601. These can be used for special identification in the taxonomy of heterocystous cyanobacteria. Three types of the STRR sequences identified are STRR1 [CCCCA(A/G)T], STRR2 [TT(G/T)GTCA] and STRR3 [CAACAGT]. Of these, the former two are present 100 copies each per *Calothrix* genome (Mazel *et al.*, 1990). These can be used as oligonucleotide probes (Rouhiainen *et al.*, 1995) or as primers for the generation of PCR-amplified DNA profiles (Rasmussen and Svenning, 1998) for the identification of toxic cyanobacteria in cultures as well as from field samples. Besides the STRR sequences, the repetitive extragenic palindrome sequences (REP) and Enterobacterial Repetitive Intergenic consensus sequences (ERIC) (Sharples and Lloyd, 1990; Hulton *et al.*, 1991; Wilson and Sharp, 2006) have been used for the identification of bacteria. DNA polymorphisms in phycocyanin locus were used to generate RAPD fingerprinting profiles to differentiate members of the genera *Anabaena* and *Microcystis* (Neilan *et al.*, 1995). Symbiotic and free-living cyanobacterial cultures were identified by PCR fingerprinting (Weiwen *et al.*, 2002) and genotypes of *Microcystis* were discriminated by RAPD fingerprinting technique (Nishihara *et al.*, 1997).

v) Terminal restriction fragment length polymorphism (T-RFLP): The fifth method is just an extension of the second method described by Liu *et al.* (1997) where the initial steps of DNA isolation, PCR amplification and digestion with restriction enzymes are similar to those used for ARDRA. However, in this method one of the primers used is labelled at 5'-terminus with a fluorescent dye and the terminal restriction fragments (T-RFs) are separated by electrophoresis and their fluorescence measured. T-RFLP analysis provides quantitative data about each T-RF detected, including size in base pairs and intensity of fluorescence (represented by peak height). Due to terminal RFLPs (T-RFLPs) found in 16S rDNAs, this method can be used with DNA from complex microbial communities. It is important to select proper PCR primers as well as restriction enzymes (Fig. 13). Computer simulated analysis of T-RFLP for 1,002 eubacterial sequences, 686 sequences could be PCR-amplified and

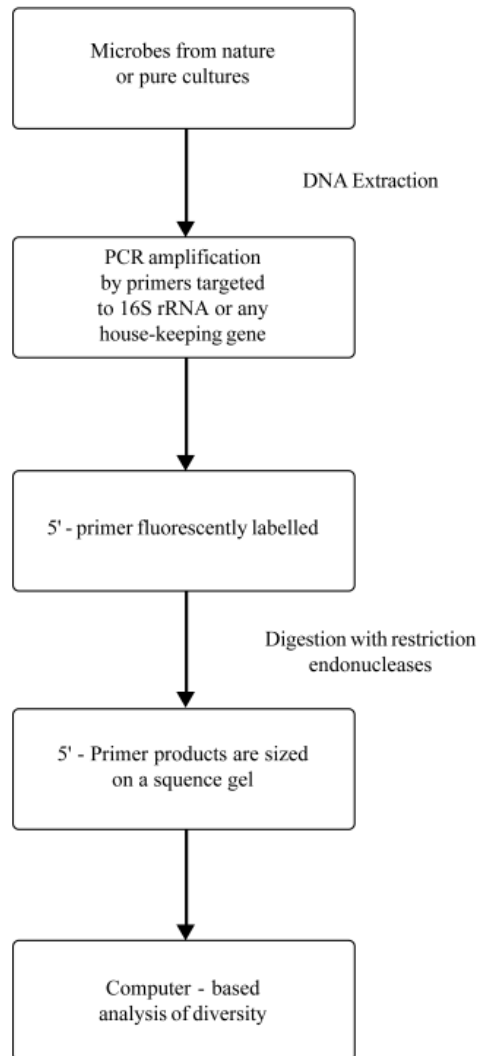


Figure 13: Flow-chart depicting different steps in T-RFLP technique.

classified into 233 unique T-RFLPs or ribotypes. Using this method, Liu *et al.* (1997) were able to distinguish all bacterial strains in a model bacterial community. It has been shown to be an effective technique for discriminating microbial communities in a range of environments (Tiedje *et al.*, 1999) and also found to be relatively stable to variability in PCR conditions (Osborn *et al.*, 2000; Ramakrishnan *et al.*, 2000). A web-based research tool for microbial community analysis was developed by Marsh *et al.* (2000) for T-RFLP analysis and was located at the Ribosomal Database Project website (<http://www.cme.msu.edu/RDP/html/analyses.html>). According to these workers, it is important to know (i) the type of restriction enzyme(s) that will provide the most discriminating activity for estimates of population diversity, (ii) the enzymes that will provide the best resolution for the best phylogenetic group and (iii) the particular primer-enzyme combination which will be optimal for the community under investigation. Each unique T-RF is considered equivalent to one OTU and so can be equated to a single species/strain within a given community (Moesender *et al.*, 2001). Thus T-RFLP technique can be used to assess spatial and temporal changes in 16S rDNAs from microbial communities (Kitts, 2001; Osborn *et al.*, 2000; Dunbar *et al.*, 2001; Sessitsch *et al.*, 2001). T-RFLP technique is highly sensitive and helpful in acquiring data very rapidly compared to other methods such as denaturing gradient gel electrophoresis (DGGE) or ARDRA (Ferris and Ward, 1997; Moesender *et al.*, 1999; Muyzer, 1999; Horz *et al.*, 2001). Blackwood *et al.* (2003) are of the opinion that T-RFLP data provide inaccurate estimates of true diversity in microbial communities. Wherever significant differences in T-RFLP diversity indices have been found, all such work should be reinterpreted by the application of a correction factor $TRF-E_{var}$ as a reflection of differences in community composition rather than a true difference in community. In addition, molecular profiling methods such as these normally represent only “dominant” organisms in the community (that constitute less than 1% of the community) and rare species are not represented. Detecting the diversity of rare species is also important because in some microbial communities the vast majority of the diversity is constituted by the rare species (Gans *et al.*, 2005; Pedrós-Alió, 2006). There is every possibility for the generation of T-RFs of the same size from multiple taxa that are distantly related. In that case, the diversity of the dominant taxa will be underestimated (Dunbar *et al.*, 2001; Engebretson and Moyer, 2003; Blackwood and Buyer, 2007). Blackwood *et al.* (2007) advocated the physical capture of T-RFLP using a biotinylated primer and streptavidin-coated beads. They were able to show that the physical capture method described by them created similar profiles such as those generated by fluorescent T-RFLP. When sequencing of such biotinylated captured T-RFs was done, most of the sequences did not match with those already present in database suggesting that these belonged to rare species, although the T-RFs were of the same size. So these workers emphasized that the T-RFs should best be identified on the basis of sequencing rather than by comparing their sizes to T-RFs of computer digests (of database sequences). They selected T-RFLP of bacterial ribosomal gene because of its popularity, availability of database of sequences and bioinformatic tools. Engebretson *et al.* (2003) explored the possibility of resolving single populations in model communities by using selected restriction endonucleases. They also measured the success of restriction endonucleases in detecting sequence variants from model communities that showed variations in species abundance. From the database of gene sequences, the restriction endonucleases have been classified on the basis of their ability to resolve T-RFs. Of the 18 restriction endonucleases tested, *Bst*UII, *Dde*I, *Sau* 96I and *Msp*I showed highest resolving potential of identifying single populations in model communities. All restriction endonucleases used by these workers could generate T-RFs of more than 70% OTUs at richness values greater than 50 OTUs per model community.

A controversy seems to have arisen on the suitability of fingerprinting methods for the community studies. While community fingerprinting methods such as automated ribosomal intergenic spacer analysis (ARISA) and T-RFLP are useful for comparative analyses, they are not useful to assess the phylotype richness or community evenness because the values for these have been found to be variable and appear to be dependent on restriction enzyme used for generating the profile. Although T-RFLP provides a rapid means for comparing the relationships between bacterial communities, it may not be suitable for highly complex communities (Dunbar *et al.*, 2000). Subsequently, these workers assessed phylogenetic relationship of every group of 16S rDNA sequences that yielded the TRFs of the same size. When replicate samples (aliquots of a single restriction digest) were compared the profiles substantially differed from one another suggesting that the results are not reproducible. However, phylogenetic inferences will be most effective if TRF profiles represent only a single bacterial division or a smaller group. The analytical precision of this method is doubtful as about 85% of the 169 TRF profiles were not reproducible when nine replicate samples from a single soil sample were analysed. Such methods are inherently limited by their detection threshold or, more precisely, by their dynamic range (Dunbar *et al.*, 2001). Danovaro *et al.* (2006) compared microbial community diversity and richness estimates obtained by using ARISA with T-RFLP of 16S rRNA genes. They showed that ARISA estimates of bacterial species richness are always higher than those obtained using T-RFLP analysis. Bent *et al.* (2007) argued that the number of peaks detected in either T-RFLP or ARISA assays grossly underestimate the actual richness of any community. According to them, the two methods cannot be treated at par, as the resolving power of each of these is different and thus can partition the community differently. Moreover, the observed categories do not correspond to the named taxonomic identities. They concluded that the “current microbial community fingerprinting methods cannot provide reliable diversity indices” and also added that it is not understandable why the investigators do not realize the limitations of such methods and hastened to add that “the emperor has no clothes”. Danavaro *et al.* (2007), however, observed that T-RFLP analysis and ARISA in fact lead us to clearly distinguishable taxonomic categories. It is now well realized that the 16S rRNA gene alone is not sufficient to define phylogenetic relationships among closely related species (Normand *et al.*, 1996; Guasp *et al.*, 2000; García-Martínez *et al.*, 2001; Song *et al.*, 2004; Brown *et al.*, 2005). In view of this, 16S rRNA-23S rRNA ITS region emerged as an important molecular marker for discrimination to the species level and even within species (Guasp *et al.*, 2000; Gonçalves *et al.*, 2002; Xu and Cote, 2003; Song *et al.*, 2004; Kwon *et al.*, 2005). The criticism of Bent *et al.* (2007) to ARISA and T-RFLP can also be extended to any fingerprinting technique including DGGE/thermal gradient gel electrophoresis (TGGE). They concluded that all fingerprinting techniques are always useful in comparing biodiversity of different habitats and ecosystems. Fingerprinting techniques are akin to prêt-à-porter clothes. Although such a dress is not as glamorous as the dress of a top stylist but the fact remains that at least “it does not leave you naked”.

vi) PCR and DGGE: The sixth method is dependent on DNA melting behavior. In DGGE, chemicals such as urea or formamide gradients are used to separate the PCR products. This has been developed by Muyzer *et al.* (1993, 1995) in which cellular/environmental DNA sample is subjected to PCR amplification by universal or specific domain primers to identify 16S rRNA gene or any other target gene. The amplified gene products are then subjected to DGGE, stained and visualized for profile and data analysis. The total number of bands represents the total community structure and each band is represented by the individual species/strain component and the intensity of the band in turn reflects the abundance of particular species/strain. This technique involves sequence-dependent separation of PCR products which can be used to assess the genotypic diversity in environmental

samples. Isolated cultures can be characterized by DGGE and can be assigned to field populations based on their DGGE profiles (Fig. 14). There are two advantages of this method. This method helps to (i) assess community structure and (ii) provides relatively crude estimates of species diversity. The disadvantages are that it involves comparative insensitive staining techniques and does not provide information concerning specific phylogenetic groups that comprise a microbial community. GC fractionation is shown to enhance bacterial community diversity assessment and the detection of minority populations of bacteria is quite feasible by DGGE. Applying this technique, Holben *et al.* (2004) subjected bacterial community DNA (total bacterial community of cecum of broiler chicken worldwide) to GC fractionation by differential density imposed by AT-dependent DNA binding dye bis-benzimidazole. Such GC-fractionated DNA was PCR amplified and subjected to DGGE analysis. By this approach, it was possible to identify a number of phylotypes that were not recovered using traditional random cloning and sequencing approach. Also directed cloning and sequencing of individual bands from DGGE lanes corresponding to G+C fractions allowed detection of numerous phylotypes that were not recovered by other traditional methods. Using PCR-DGGE, total community structure of cyanobacteria has been determined in the mats inhabiting the intertidal

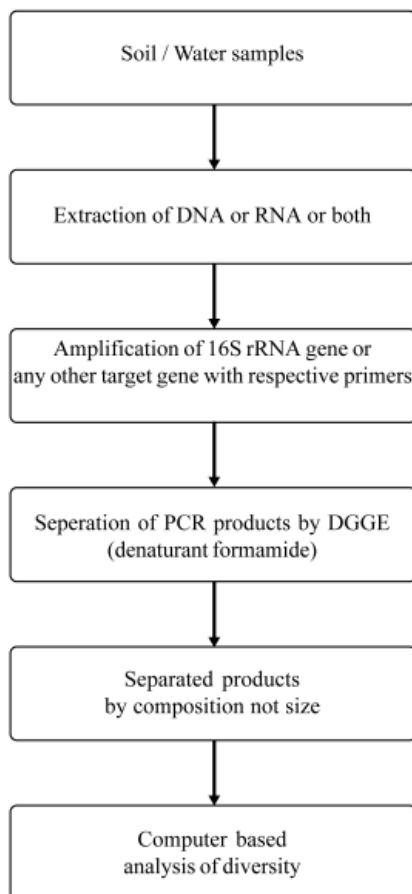


Figure 14: Flow-chart showing different steps in PCR-DGGE.

zone of oil-polluted coast of Saudi Arabia (Al-Thukair *et al.*, 2007). This technique can provide a wealth of information on the spatio-temporal distribution of soil microorganisms and solve ecological puzzles relating to their nutritional interactions (Nakatsu, 2007). DGGE profiles of rRNA ITS region have helped in understanding genotypic variation in *Microcystis* species in relation to microcystin concentration in freshwater lakes (Kardinaal *et al.*, 2007).

vii) DNA microarray technology: It is potentially a valuable tool for quantitative, systematic and detailed studies of microbial communities. It can measure thousands of distinct DNA sequences simultaneously and requires a low sample size. Identification of microbes can be based on PCR amplification of rDNA genes with the help of oligonucleotide primers or native rRNAs hybridized to oligonucleotide microarrays. Initial studies were mainly based on small-scale microarrays for profiling specific bacterial species of interest from diverse environments (Guschin *et al.*, 1997; Small *et al.*, 2001; Koizumi *et al.*, 2002; Liu *et al.*, 2001; Loy *et al.*, 2002; Wang *et al.*, 2002, 2004; Castiglioni *et al.*, 2004). El Fantroussi *et al.* (2003) assessed environmental microbial populations by extracting directly rRNA and hybridizing with oligonucleotide microarrays without PCR amplification. The hybridization patterns were reproducible and exhibited variation in eustuarine sediments differing in salinities. A thermal denaturation curve (i.e. melting profile) for each probe-target duplex indicated the specificity of hybridization. Palmer *et al.* (2006) designed 10,462 16S rDNA probes (of which 7167 are unique sequences) for recognition of diverse microbial populations through this technique. Bacterial species occurring in less than 0.1% in complex mixtures could be easily identified. The microbial diversity assessed with this technique is comparable to the community profile revealed with 16S rDNA sequences of the same species. So this technique is quite well suited to characterize complex microbial communities. The advantages of this technique are that it is quite rapid, reproducible and can even detect bacterial species missed by sequencing of >600 clones. However, the limitations of this technique are that it can only detect species and taxonomic groups for which probes have been successfully designed and it cannot directly discover novel species which can only be possible by the sequencing technique.

By the application of the above molecular techniques, the taxonomy and phylogeny of various cyanobacteria has been investigated *in vitro* (based on cultures) and *in vivo* (field samples). In many cases a correlation has been done between the cultures and field samples.

3) 16S rRNA gene sequencing in cyanobacteria

Cyanobacteria form a monophyletic cluster among eubacteria (Woese, 1987; Garrity and Holt, 2001). The cyanobacterial cluster also contains the plastids of eukaryotes (Giovannoni *et al.*, 1988; Wilmotte and Golubic, 1991; Turner, 1997). Based on phylogenetic analysis of the 16S rRNA gene sequences it has been concluded that the diversification of cyanobacteria occurred within a short time (Giovannoni *et al.*, 1988; Wilmotte and Herdman, 2001). Another important evolutionary event is the recognition of the polyphyletic nature of the Prochlorophyta (Urbach *et al.*, 1992) and their clustering with cyanobacteria (Wilmotte, 1994; Palenik and Swift, 1996). This suggests that the Prochlorophyta and cyanobacteria shared a common ancestor and the recognition of Prochlorophyta as a separate group. Dideoxynucleotide-terminated sequencing, using reverse transcriptase and oligodeoxynucleotide primers (complementary to *E. coli* 16S rRNA sequence positions 519 to 536, 907 to 926, 1392 to 1406 bp) revealed that unicellular cyanobacteria of Section I and the non-heterocystous, filamentous organisms of Section III are dispersed through out the phylogenetic tree suggesting that these morphotypes have multiple evolutionary origins. This is not consistent with

their traditional classification. However, heterocystous cyanobacteria form a monophyletic cluster or group (Giovannoni *et al.*, 1988; Turner, 1997; Wilmotte and Herdman, 2001). This group includes members of both Sections IV and V defined by Rippka *et al.* (1979) corresponding to the orders Nostocales and Stigonematales, respectively under ICBN.

A number of workers have put forward proposals for the recognition of phylogenetic lineages or clusters that are not consistent with the classifications under ICBN or that of Rippka *et al.* (1979) or the Bergey's Manual. Wilmotte and Herdman (2001) recognised 14 phylogenetic clusters among cyanobacteria mainly based on 16S rRNA gene sequencing. This formed a part of Bergey's Manual. Other workers recognized seven (Honda *et al.*, 1999), ten (Turner *et al.*, 1999) and five (Seo and Yokota, 2003; Tomitani *et al.*, 2006) phylogenetic clusters among cyanobacteria. They took into account sequence comparisons of a number of housekeeping genes besides 16S rDNA sequences to draw phylogenetic relationships. These are presented below.

Honda *et al.* (1999) detected seven major evolutionary lineages in cyanobacteria (including Prochlorophycean algae) based on 16S rRNA gene sequence analysis which has further been supported by phylogenetic relationships based on other genes such as *psbA*, *rbcL*, *rnpB*, *rpoC* and *tufA*. Five new *Synechococcus* 16S rRNA gene sequences (belonging to *Synechococcus* PCC 7001, PCC 7003, PCC 7109, PCC 7117 and PCC 7335) have been assigned to Marine Cluster (MC)-B and MC-C but were separated into three lineages. They suggested that organisms classified in the genus *Synechococcus* have evolved diversely and should be reclassified into several independent taxonomic units. Further, the *Synechococcus* strains and filamentous cyanobacteria make a monophyletic group reflecting a convergent evolution of multicellular organization.

Turner *et al.* (1999) recognized 10 monophyletic clusters in cyanobacteria based on 16S rRNA gene sequence analysis. *Nostoc* (NOST), *Pseudoanabaena*, *Oscillatoria* (OSC) and *Synechococcus* clusters were common in the studies of Turner *et al.* (1999) and those studied by Tomitani *et al.* (2006). The *Synechocystis*/*Pleurocapsa*/*Microcystis* sequence group identified by Turner *et al.* (1999) does not derive much support from the work of Tomitani *et al.* (2006), although *Prochloron* and *Pleurocapsalean* cyanobacteria formed a cluster. Turner *et al.* (2001) compared phylogeny, based on 16S rRNA gene sequencing by using ML method, of strains of nitrogen-fixing unicellular cyanobacteria. Three independent lines of descent have been identified without any correlation between aerobic versus anaerobic nitrogen-fixing activity. *Cyanothece* PCC 7418 has a sequence similarity of 100% with the strains assigned to *Dactylococcopsis* and *Euhalothece*. Strains assigned to *Cyanothece* are polyphyletic with four strains (including *Synechococcus* RF-1 that has been redesignated as *Cyanothece* PCC 8801) falling into three distinct sequence clusters containing strains assigned to other genera.

Tomitani *et al.* (2006) conducted a detailed phylogenetic analyses of 20 cyanobacterial strains belonging to 15 diverse representative filamentous taxa on the basis of 16S rRNA, *rbcL* and *hetR* gene sequences in which comparison between ML, NJ and MP methods has been made. Filamentous cyanobacteria belonging to subsection III appear to be mixed with unicellular species of the subsections I and II indicating their polyphyletic origin. Further certain of the strains e.g. *Prochloron* and those belonging to subsection II form clusters in all the trees constructed with ML, NJ and MP methods. Heterocystous cyanobacteria of subsections IV and V form a monophyletic clade in phylogenetic trees constructed by the ML and NJ methods (with a bootstrap value of 97%) and to a lesser extent by MP method where the bootstrap values of 66% were found. Further the monophyly of heterocystous cyanobacteria is supported by *rbcL* phylogeny in all the three phylogenetic trees constructed by NJ, MP and ML methods. Likewise, the phylogenetic analysis based on *hetR* gene supports the monophyly of subsection V by NJ and MP methods with bootstrap values of 99% and

96% respectively. The monophyletic nature of subsection V in *hetR* trees is consistent with 16S rRNA phylogeny but not with analyses of *rbcL*, *nifH* and *nifD* phylogenies.

Wilmotte and Herdman (2001) considered that it is quite premature to treat taxonomy of cyanobacteria on a phylogenetic basis. They further cautioned that due to two reasons the studies on taxonomy and molecular phylogeny of cyanobacteria suffered a set back. The first is that certain strains of cyanobacteria investigated from culture collections have not been properly identified and secondly, the data on 16S rRNA sequences on some strains originated from morphologically unidentified members. That is why the identification of a cyanobacterium on polyphasic approach should be done first before initiating studies on molecular phylogeny. Another important aspect is to have as much ecological information as possible on cyanobacteria at the time of collection and identification on a polyphasic approach. For this would greatly help in the diversity assays of cyanobacteria from different environments based on molecular markers and even if some sequences have been identified on the basis of culture independent approach, they can then be assigned to a probable strain of close proximity based on the habitat. Wilmotte and Herdman (2001) have identified 14 lineages or clusters in cyanobacteria by comparing 16S rRNA gene sequences and phylogenetic relationships drawn on the basis of ML and NJ methods and bootstrap analysis involved 500 resamplings. These are as follows: (i) heterocystous cluster, (ii) *Prochlorococcus marinus*, *Synechococcus*, *Cyanobium* and the sequences from the Sargasso Sea; (iii) *Prochlorothrix hollandica* lineage, (iv) the marine *Leptolyngbya* lineage, (v) freshwater "*Leptolyngbya*" lineage, (vi) the *Pseudoanabaena* cluster, (vii) the halotolerant unicellular strains, (viii) the lineage of baeocyte-forming strains, (ix) the *Spirulina* cluster, (x) *Synechococcus* PCC 7002 and *Leptolyngbya fragile* PCC 7376 lineage, (xi) the *Synechocystis* PCC 6906-*Microcystis* lineage, (xii) the *Trichodesmium-Oscillatoria* PCC 7515 lineage, (xiii) the *Arthrospira* lineage and (xiv) the *Geitlerinema* lineage. Of these 14 clusters, cluster (vii) comprising the halotolerant strains has been suggested to be quite unique that is based on a polyphasic approach. Garcia-Pichel *et al.* (1998) compared the morphological, physiological features and 16S rRNA gene sequences of unicellular, extremely halotolerant and moderately thermophilic cyanobacteria. All these share a number of chemotaxonomic markers including phycobilins, carotenoids and possess mycosporine-like amino acids as well. These are variable in their cell size and form colonies that exhibit two planes of division and reproduce by baeocyte formation (strains MPI 96N303 and MPI 96N304). Some are colonial but do not reproduce by baeocytes and cells divide in a single plane (MPI 96P402, MPI 96P605, MPI 96AL03 and MPI 96AH13). Besides these, *Cyanothece* PCC 7418, *Dactylococcopsis* PCC 8305, *Aphanothece halophytica* ATCC 43922, *Cyanothece* MPI 95AH10 are also included in this analysis. Taxonomically, all strains possibly belong to *Cyanothece* according to Castenholz and Waterbury (1989) but *Aphanothece* or *Cyanothece* according to Anagnostidis and Komárek (1986). On the basis of NJ phylogenetic tree analysis all these strains are placed in a monophyletic cluster. This is the first group of cyanobacteria that are closely related with each other on the basis of 16S rRNA gene sequencing and a set of physiological characteristics. According to Wilmotte and Herdman (2001) this study 'is a nice example of a polyphasic approach to the taxonomy of cyanobacteria'.

Seo and Yokota (2003) have drawn comprehensive phylogenetic relationships amongst cyanobacteria (consisting of 3 strains of Chroococcales, 5 strains of Pleurocapsales, 7 strains of Oscillatoriales, 7 strains of Nostocales and 2 strains of Stigonematales) based on 16S rRNA, *gyrB* (DNA gyrase subunit B), *rpoC1* (DNA-dependent RNA polymerase γ -subunit) and *rpoD1* (principal σ factor of *E. coli* σ^{70} type DNA-dependent RNA polymerase) gene sequences that revealed 5 subgroups of cyanobacteria. They designed PCR primers for *gyrB*, *rpoC1* and *rpoD1* genes by using consensus amino acid sequences registered in GenBank. Phylogenetic relationships drawn based on *gyrB*, *rpoC1* and *rpoD1* sequences supported 16S rRNA gene sequence based phylogeny. Phylogenetic trees

based on sequences of these genes and the combined amino acid sequences deduced from *rpoC1* and *rpoD1* suggested that LGT of rRNA might be suspected in case of *Synechocystis* sp. strain PCC 6803. The 24 cyanobacterial sequences have been resolved into five clusters (A-E). Cluster A comprises sequences from *Anabaena cylindrica*, *Anabaena variabilis*, *Anabaenopsis circularis*, *Chlorogloeopsis* sp. PCC 6718, *Chroococcidiopsis* sp., *Fischerella muscicola* and *Nodularia spumigena*. Cluster B consists of *Oscillatoria agardhii*, *Oscillatoria nigro-viridis*, *Phormidium* sp. and *Spirulina platensis* while Cluster C is composed of *Microcystis wesenbergii* NIES-104, *Pleurocapsa* sp. PCC 7327, *Pleurocapsa* sp., *Stanieria cyanosphaera* PCC 7437, *Synechocystis* sp. strain PCC 6803 and *Xenococcus* sp. Cluster D consists of *Pseudoanabaena* sp. PCC 7367, *Pseudoanabaena* sp. PCC 7403 and *Synechococcus* sp. PCC 7001. Cluster E is represented by *Leptolyngbya* PCC 7375 and *Synechococcus leopoliensis* IAMM-6.

A number of studies have been devoted to resolve taxonomic disparities and also draw phylogenetic relationships amongst different groups of cyanobacteria. Of the 14 clusters recognized on the basis of 16S rRNA gene sequences in cyanobacteria (Wilmotte and Herdman, 2001), such attempts were made with cyanobacteria belonging to six clusters. The taxonomic resolution of strains of cluster I comprising of heterocystous members (*Anabaena*, *Aphanizomenon*, *Cylindrospermopsis*, planktic *Anabaena*, *Planktothrix*), cluster II of *Synechococcus*, cluster V of freshwater *Leptolyngbya* lineage, cluster VI of *Pseudoanabaena*, cluster XII of *Trichodesmium-Oscillatoria* PCC 7515 lineage and cluster XIV of *Geitlerinema* lineage has been undertaken during recent years. These are summarized below.

i) Heterocystous cyanobacterial cluster: (Cluster I as per Wilmotte and Herdman, 2001): Studies on the phylogeny of the heterocystous cyanobacteria based on 16S rRNA gene sequencing revealed that these form a monophyletic cluster or group (Giovannoni *et al.*, 1988; Turner, 1997; Wilmotte and Herdman, 2001). Within this cluster, phylogenetic relationships of planktonic heterocystous cyanobacteria based on the 16S rRNA gene sequence comparisons (Lyra *et al.*, 1997; 2001; Barker *et al.*, 1999; Beltran and Neilan, 2000; Lehtimäki *et al.*, 2000; Li *et al.*, 2000; Moffit *et al.*, 2001; Saker and Neilan, 2001), DNA-dependent RNA polymerase gene (*rpoC1*; Fergusson and Saint, 2000; Wilson *et al.*, 2000), the intergenic spacer region of the phycocyanin operon (PC-IGS; Neilan *et al.*, 1995; Baker *et al.*, 1999; 2000; Bolch *et al.*, 1999) and the IGS between two copies of the *gvpA* encoding major structural gas vesicle protein (Barker *et al.*, 1999) have been drawn. The extent of morphological diversity among the planktonic heterocystous members has been depicted (Figs. 15, 16 and 17). Itean *et al.* (2002) reported the existence of five monophyletic clusters among heterocystous cyanobacteria. Cluster I comprises forms assigned to *Anabaena* and *Aphanizomenon*. Cluster II comprises strains of *Anabaena*. Cluster III is composed of *Anabaena circinalis* and *A. affinis* (Beltran and Neilan, 2000). Cluster IV and V possess planktonic and non-planktonic strains of *Nodularia* and *Cylindrospermopsis raciborskii*, respectively. Although on the basis of morphological characteristics or heterocyst differentiation patterns the members of the last two clusters can be identified but 16S rRNA gene sequence similarity is so high that all of them can be assigned to a single species. Alternatively, it can also be stated that the resolving power of the 16S rRNA is not sufficient enough to make a distinction of these members. Keeping this in view, Itean *et al.* (2002) compared the 16S rRNA gene sequences and the 16S rRNA-23S rRNA ITS sequences of 11 planktonic members (*Anabaenopsis flos-aquae* PCC 9302, PCC 9332, PCC 9349, PCC 7905; *Anabaenopsis* sp. strains PCC 9215, PCC 9216, PCC 9608, *Anabaenopsis elenkinii* PCC 9420, *Cyanospira capsulata* PCC 9502, *Cyanospira rippkae* PCC 9501 and *Nodularia* sp. PCC 9350) that formed a distinct subclade within the monophyletic clade of heterocystous cyanobacteria with the exception of strains of *Cylindrospermopsis*. Five distinct phylogenetic clusters could be identified within this subclade. Strains of *Anabaena* and *Aphanizomenon* are dispersed through three clusters

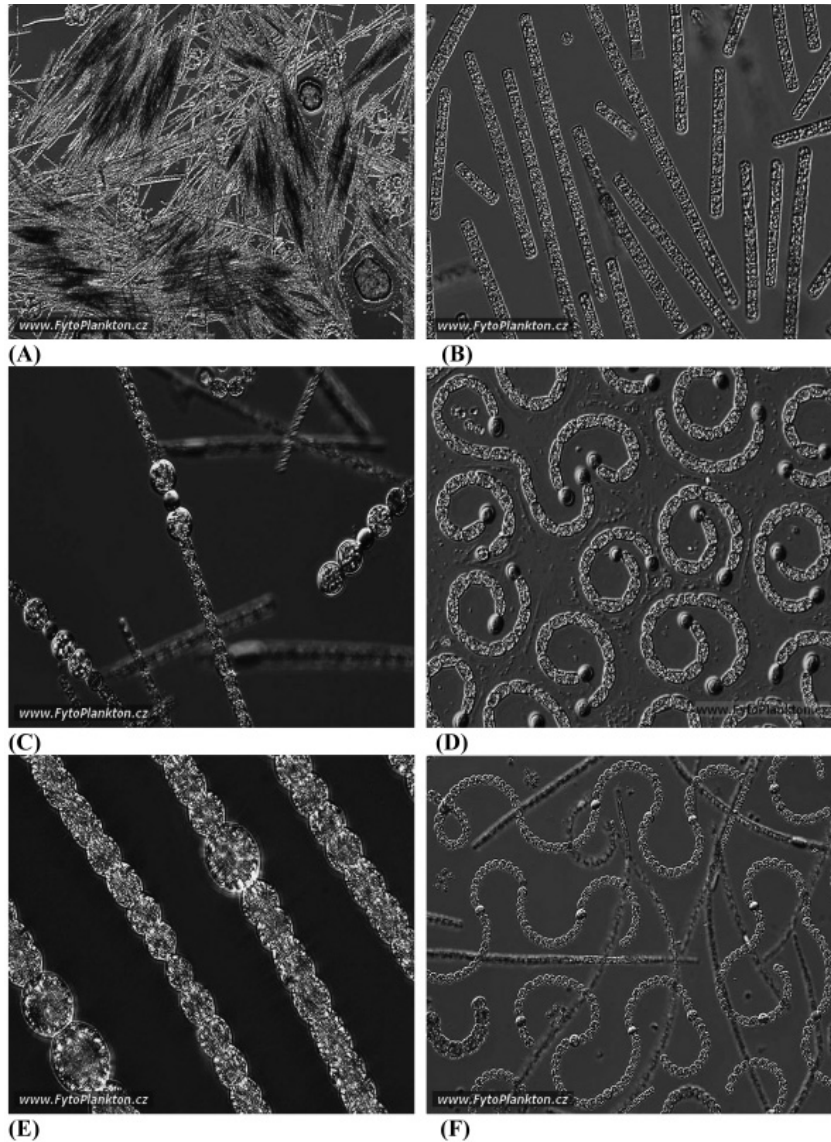


Figure 15: Representatives of planktonic cyanobacteria from different water bodies of Czech Republic. Colonies (A, 300x) and individual filaments (B, 600x) of *Aphanizomenon klebahnii*; *Aphanizomenon aphanizomenoides* (C, 600x), *Anabaenopsis cf. elenkinii* (D, 400x), *Anabaena planctonica* (E, 300x), and *Anabaena flos-aquae* (F, 300x). All are Nomarski contrast images downloaded from www.FytoPlankton.cz with the kind permission of Dr. P. Znachor, Laboratory of Phytoplankton Ecology, Institute of Hydrobiology, Biology Centre, ASCR, Na Sádkách, 37005 České Budějovice, Czech Republic.

that are totally not consistent with their generic and species identities. However, all the heterocystous strains contained up to five *rrn* operons with variable ITS regions in all the taxa investigated. As observed in case of bacteria, in cyanobacteria too, the RB values and 16S rRNA sequence similarity are at variance (Lachance, 1981). Iteman *et al.* (2002) showed that two strains of *Nodularia*, i.e. *Nodularia* PCC 7804 and PCC 7314 exhibited 98.3% 16S rDNA sequence similarity but only 65% RB (ΔT_m 6

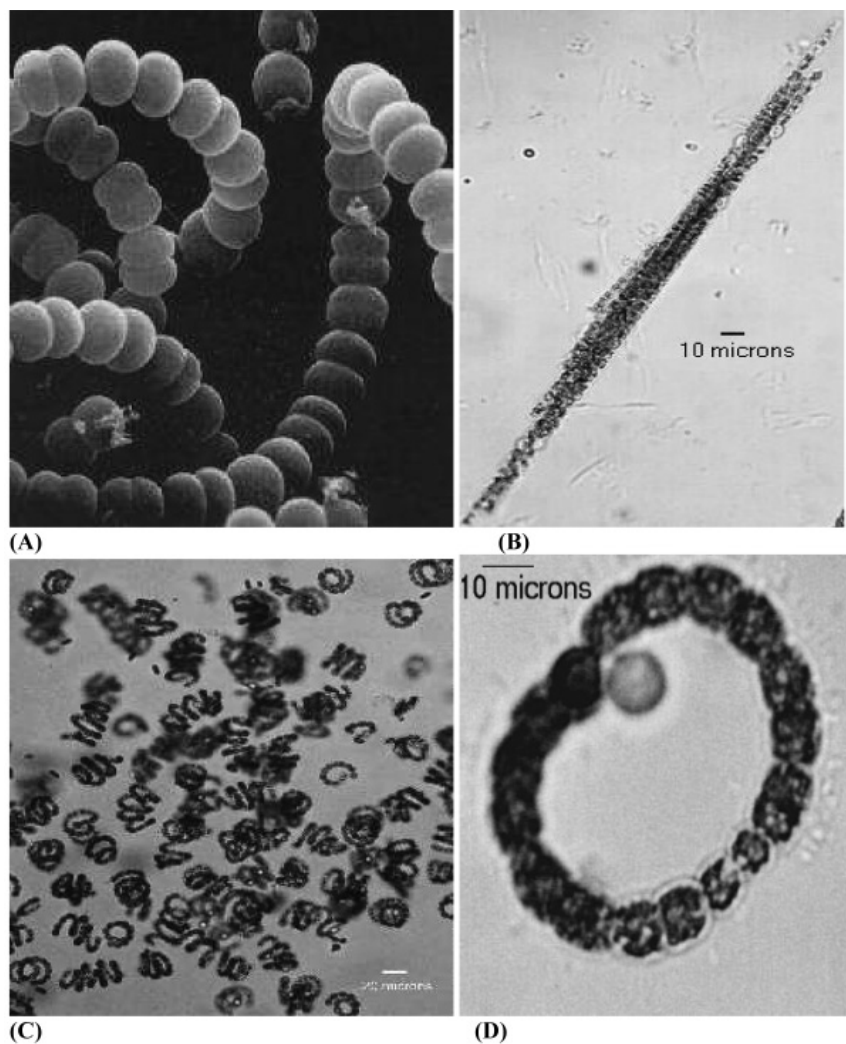


Figure 16: *Anabaena flos-aquae* (A), *Aphanizomenon flos-aquae* (B), *Anabaena spiroides* (C) and *Anabaenopsis circularis* (D). Magnification of A is $\times 2500$ in the rest the magnification bar represents 10 μm (B and D) and 20 μm (C). Picture A courtesy Wayne Carmichael (Wright State University), Mark Schneegurt (Wichita State University) and Cyanosite (www.cyanosite.bio.purdue.edu) and. Pictures B, C and D courtesy of Roger Burks (University of California at Riverside), Mark Schneegurt (Wichita State University) and Cyanosite (www.cyanosite.bio.purdue.edu).

$^{\circ}\text{C}$). In contrast, *Calothrix* sp. strains PCC 7102 and PCC 7709 exhibited a lower 16S rDNA sequence similarity (96.4%) but higher RB (74%) at ΔT_m 4°C . *Anabaena* PCC 7804 exhibited 95.1% and 95.6% 16S rDNA similarity with *Cylindrospermum* PCC 7417 and *Nodularia* PCC 7804 but the total DNA homology is 23% and 19%, respectively. Due to the complexity involved in the clustering of the strains of *Anabaena* and *Aphanizomenon*, a phylogenetic comparison of these two genera (26 strains of the former and 14 strains of the latter) based on sequencing of 16S rRNA gene, 16S rRNA-23S rRNA ITS1 region and *rbcXL* gene has been done by Gugger *et al.* (2002). Planktic *Anabaena* strains were indistinguishable from *Aphanizomenon*. These two genera have been found to be polyphyletic

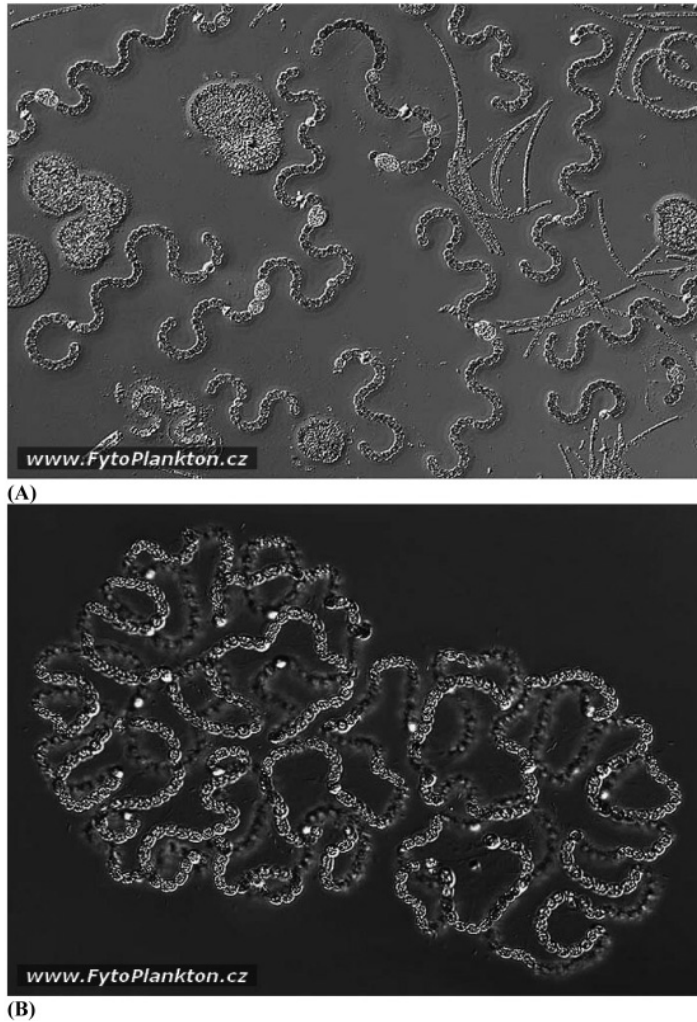


Figure 17: Representatives of planktonic cyanobacteria from different water bodies of Czech Republic. Nomarski contrast pictures of *Anabaena crassa* (A) and *Anabaena lammermannii* (B) with a magnification of both at x200. Pictures courtesy P. Znachor, Laboratory of Phytoplankton Ecology, Institute of Hydrobiology, Biology Centre ASCR, Na Sádkách, 37005 České Budějovice, Czech Republic, www.FytoPlankton.cz.

on the basis of comparison of 16S rRNA gene sequences. The sequencing of *ITS1* and *rbcXL* regions showed that planktic *Anabaena* is heterogeneous as the toxic *Anabaena* strains were clustered together in all methods of analyses but were grouped with non-toxic *Anabaena*/*Aphanizomenon* strains. Due to their molecular proximity, strains of planktic *Anabaena* and *Aphanizomenon* isolates appear to belong to the same genus, despite their morphological differences. Accordingly, this necessitates a taxonomic revision of these two genera.

Gugger and Hoffmann (2004) presented evidences for polyphyletic nature of true branching cyanobacteria (belonging to subsection V of cyanobacteria of Bergey's Manual and order Stigonematales). Strains belonging to the genera *Fischerella* (Born. et Flah.) Gom.1895 (*F. muscicola*

PCC 7414, *Fischerella* sp. 1711 and *Fischerella* sp. SAG 2027) *Hapalosiphon* Näg. in Kütz. ex Born. et Flah. 1886 (*Hapalosiphon* sp. 804-1), *Mastigocladopsis* Iyeng. et Desik. 1946 (*Mastigocladopsis repens* MORA), *Nostochopsis* Wood. ex Born. et Flah. 1886 (*Nostochopsis* sp. 89-45), *Stigonema* Ag. ex Born. et Flah. 1886 (*Stigonema ocellatum* SAG 48.90), *Symphyonema* Jao 1944 (*Symphyonema* sp. 1269.1 and *Symphyonema* sp. 1517), *Symphyonemopsis* Tiwari et Mitra 1969 (*Symphyonemopsis* sp. VAPOR1) and *Westiellopsis* Janet 1941 (*Westiellopsis prolifica* SAG 16.93, *Westiellopsis* SAG 23.96, *Westiellopsis* sp. 1590-1, *Westiellopsis* sp. 1590-2, *Westiellopsis* sp. 89-785/4 and *Westiellopsis* sp. 985-1) have been selected that differed from one another in the type of branching (Y vs T-branching) and the position of heterocysts (intercalary, lateral-sessile and lateral-pedicellate). A phylogenetic study of these strains based on 16S rRNA gene sequencing following NJ method revealed four clusters (Clusters 1, 2, 3 and 5). Clusters 2 and 3 are always basal to Cluster 1 and all these exhibit T-branching whereas Cluster 5 is composed of Y-branching types such as *Symphyonema* and *Symphyonemopsis*. These results do not correlate with the traditional as well as bacteriological classifications. Other heterocystous unbranched members (*Nodularia*, *Anabaena*, *Aphanizomenon*, *Nostoc*, *Cylindrospermopsis*) are present in Cluster 4 whereas *Scytonema hofmanni* PCC 7110 and *Scytonema* sp. are present in Cluster 6.

Rajaniemi *et al.* (2005) investigated the molecular phylogeny of heterocystous cyanobacteria and included *Anabaena*, *Aphanizomenon*, *Trichormus* and *Nostoc* in their study. Most of the 51 strains selected were representatives of the planktic *Anabaena* and *Aphanizomenon*. The former was represented by 10 species (*A. crassa* (Lemm.) Kom.-Legn. et CronB., *A. circinalis* Rabenh. ex Born. et Flah., *A. planctonica* Brunth., *A. mucosa* Kom.-Legn. et Eloranta, *A. spiroides* Kleb., *A. smithii* (Kom.) M. Watan., *A. sigmoidea* Nyg., *A. flos-aquae* [Lyngb.] Bre 'b. ex Born. et Flah., *A. cf. circinalis* var. *macrospora* and *A. lemmermannii* Richt) while the latter by three species [*Aph. flos-aquae* Ralfs ex Born. et Flah., *Aph. gracile* (Lemm.) Lemm. and *Aph. issatschenkoi* (Usač) Prošk.-Lavr.] as identified according to traditional morphological criteria (Geitler, 1932; Desikachary, 1959; Komárek and Anagnostidis, 1989). It is pertinent to mention here that the genus *Trichormus* was created by Komárek and Anagnostidis (1989) by transferring three species of *Anabaena* (*A. variabilis* Born. et Flah., *A. azollae* Strasb. and *A. doliolum* Bharadw.) on the basis of akinete development. In addition, nine benthic species of *Anabaena* and three of *Trichormus* (*T. variabilis* (Born. et Flah.) Kom. et Anag., *T. azollae* (Strasb.) Kom. et Anag., *T. doliolum* (Bharadw.) Kom. et Anag) and *Nostoc* sp. have been included based on traditional morphological criteria. On the basis of 16S rRNA, *rpoB* and *rbcLX* gene sequence phylogenetic analyses, Rajaniemi *et al.* (2005) identified six clusters. Cluster I is characteristic in consisting of *Anabaena* and *Aphanizomenon* strains as well as five benthic *Anabaena* strains (BECID22, BECID32, XP6B, Itu34S7 and 277) that lack gas vesicles got intermixed with planktic *Anabaena* and *Aphanizomenon* in Cluster I with high bootstrap support. These results thus do not support the separation of planktic and benthic *Anabaena* / *Aphanizomenon* strains as has been done earlier by Iteman *et al.* (2002) who found a subcluster of planktic heterocystous cyanobacteria with the exception of *Cylindrospermopsis*. Cluster I is further subdivided into nine subclusters (i.e. A-I). On the basis of cutoff points suggested for bacterial species and genus, 97.5% and 95% 16S rRNA sequence identity, respectively, these can be divided into more than three (or up to nine) species. NJ method based on 16S rRNA gene sequences showed clustering of *Anabaena*, *Aphanizomenon*, *Trichormus* and *Nostoc* with bootstrap support of over 65% for NJ, MP and ML methods of analyses. Studies on principal component analysis of morphological characters revealed that shape and size of akinetes afforded an important parameter for differentiating *Anabaena*, *Aphanizomenon*, *Trichormus* and *Nostoc* strains. The species of *Trichormus* recognised by Komárek and Anagnostidis (1989) did not form a monophyletic cluster. Accordingly, the three species of *Anabaena* transferred by Komárek and Anagnostidis (1989) to designate *Trichormus* probably are distinct species. It is interesting to note that benthic *Anabaena* /

Trichormus strains were placed outside Cluster I which contained all planktic and five benthic *Anabaena* as well as *Aphanizomenon* strains.

Restriction analysis of 16S-23S ITS region has been put to use for phylogenetic analysis of strains of non-photosynthetic eubacterial genera (Navarro *et al.*, 1992; Vinuesa *et al.*, 1998), cyanobacteria belonging to various orders (Lu *et al.*, 1997) and among the genera of heterocystous cyanobacteria (West and Adams, 1997). Iteman *et al.* (2002) determined the 16S rDNA sequences (*A. flos-aquae* PCC 9302, PCC 9332, *Aph. flos-aquae* PCC 7905, *Nodularia* PCC 9350, *Anabaenopsis* sp. PCC 9215 and *Cyanospira rippkae* PCC 9501) and the phylogenetic trees based on both ML and distance-based methods yielded similar results. With the exception of *C. raciborskii* all the strains could be assigned to five clusters. Although 16S rRNA sequence comparisons justify generic assignments but this is not suitable for resolving differences below the level of genus (Turner, 1997). But on the basis of 16S rRNA sequence comparisons a close relationship existed between *Aphanizomenon* and toxic *Anabaena* strains from various geographical locations. The RFLP patterns of PCC strains studied by these workers do not justify their generic separation into *Anabaena flos-aquae* and *Aph. flos-aquae* as has been done on the basis of morphological grounds or 16S rDNA sequences. Some other workers also found closer relationships between strains of *Anabaena* and *Aphanizomenon* based on 16S rDNA RFLP studies (Lyra *et al.*, 1997, 2001; Lehtimäki *et al.*, 2000). Strains of *Nodularia* clustered with the strains of *Anabaena* and *Aphanizomenon* based on sequences of 16S rDNA as well as RFLP studies presented by Iteman *et al.* (2002) though the *Nodularia* strains found to group with strains of genus *Nostoc* (Lyra *et al.*, 2000; Lehtimäki *et al.*, 2000). Komárek and Komárková (2006) suggested that on the basis of close resemblances of planktonic *Anabaena* strains to those of *Aphanizomenon* based on molecular phylogenetic analyses (Iteman *et al.*, 2002; Gugger *et al.*, 2002; Rajaniemi *et al.*, 2005a,b; Willame *et al.*, 2006) the generic name *Aphanizomenon* should be retained as the valid name for this large polymorphic group consisting of all planktonic *Anabaena* and *Aphanizomenon* strains. But according to combined morphological and molecular criteria, the group is so morphologically diversified that can be divisible into different generic units (*Aph. flos-aquae*, *Aph. gracile*, *Aph. issatschenkoi* and *Aph. volzii*-sub-clusters) with 16S rDNA sequence similarity of about or less than 95%. These conclusions derive support from the work of Wu *et al.* (2010) who conducted morphological identification of 53 strains of *Aphanizomenon* from China and assigned them to three morphotypes, i.e. *Aph. flos-aquae*, *Aph. gracile* and *Aph. issatschenkoi*. Phylogenetic analysis of the strains based on concatenated alignment of 16S rDNA, *rbcLX* and *cpcBA*-IGS sequences led the recognition of three clades corresponding to the three morphotypes.

ii) *Synechococcus* cluster: (Cluster II as per Wilmotte and Herdman, 2001): Six strain clusters of *Synechococcus* have been defined by Waterbury and Rippka (1989) based primarily on differences in G+C content (mol%) and habitat (freshwater and marine). These strain clusters represent provisional genera and are designated as follows: *Cyanobacterium* cluster; *Synechococcus* cluster, *Cyanobium* cluster, MC-A, MC-B and MC-C. *Synechococcus* isolates maintained at the Pasteur Collection Centre (PCC) have been divided into five clusters that do not correspond with the above six clusters. (Rippka and Herdman, 1992). Cultured *Synechococcus* strains from Japanese lakes and those from PCC were subjected to PCR amplification and DNA sequencing of 16S rDNA and the *cpcBA*-IGS and the flanking regions by Robertson *et al.* (2001). A phylogenetic analysis of *Synechococcus* strains revealed seven clusters that reflected phycobilin content. One strain of *Synechococcus* (PCC 7902) that stands apart is only loosely affiliated to cyanobacterial lineage where no other cyanobacterial sequences were found. An additional cyanobacterial lineage is represented by two hot spring *Synechococcus* isolates (PCC 6716 and PCC 6717), with these *Synechococcus elongatus* (Toray) PCC 6301 and other strains are grouped

together. These results signify that the genus *Synechococcus* is not monophyletic as was stated earlier by Urbach *et al.* (1998) and Honda *et al.* (1999). According to Robertson *et al.* (2001), *Synechococcus* sp. strain PCC 6716 and *Synechococcus* sp. strain PCC 6717 should be classified as members of a different genus from that of *Synechococcus* sp. strain PCC 6301. These may represent early morphological types of cyanobacteria and forerunners for the evolution of other cyanobacterial morphological types. In this connection, it is important to know that *Synechococcus* sp. strains PCC 6716 and PCC 6717 and *S. elongatus* (Toray) have been isolated from hot springs. However, as per Bergey's Manual of Systematic Bacteriology, *Synechococcus* sp. strains PCC 6716 and PCC 6717 represent members of the same species as *Synechococcus* PCC 6301. They retained the seven lineages described by Honda *et al.* (1999) and added an eighth one for the *S. elongatus* (Toray), *Synechococcus* sp. strains PCC 6716 and PCC 6717. Of the other groups, Group 6 is most complex and consists of three subgroups 6a, 6b and 6c. Group 6a comprises of *Synechococcus* isolates from saline lakes of Antarctica and strains of *Synechococcus* from MC-A and MC-B (PCC 7805, WH 8103, and WH 8101; Vincent *et al.*, 1999). Group 6b includes strains from MC-B and *Cyanobium* cluster. Along with these, strains of MC-A (*Synechococcus* PCC 7805 and WH 8103) and *Prochlorococcus marinus* also fall into this subgroup (Honda *et al.*, 1999; Vincent *et al.*, 1999). Subgroup 6c includes three strains of *Synechococcus* sp. (PCC 6301, PCC 7942 and PCC 7943) and species of *Microcystis* (*M. elebens* NIES 42 and *M. holsatica* NIES 43, now treated as members of *Synechococcus*) that lack gas vacuoles. They further preferred the creation of new genera for the subgroups 6a, 6b and 6c that contain most of the *Synechococcus* isolates and also for *Synechococcus* members forming group 8. They concluded that some of the members of *Synechococcus* are misclassified members (such as PCC 7902 found in group 4, PCC 7309, PCC 7117, PCC 7002 found in group 5 and PCC 7335 present in group 7).

Fuller *et al.* (2003) identified three new novel clades of *Synechococcus* on the basis of 16S rDNA sequencing. One of these clades contains halotolerant isolates lacking PE and strains that are not capable of utilizing nitrate as sole source of nitrogen. This clade is clustered with MC-A. Cloning and sequencing of the two copies of 16S rRNA of genes present in *Synechococcus* sp. strain WH 7803 and a comparison of the same with *Synechococcus* sp. strain WH 8102 revealed them to be identical. *In situ* community structure of marine *Synechococcus* populations in the Red Sea, at the time of their abundance, predominantly was represented by genotypes of a single clade and these are common representatives isolated into culture. These accounted for a very minor component of *Synechococcus* population diversity. *Prochlorococcus* contains divinylchlorophyll *a* (Chl a_2) and both monovinyl and divinylchlorophyll *b* as the major photosynthetic pigment in contrast to chlorophyll *a* and phycobiliproteins that are typical of cyanobacteria (Chisholm *et al.*, 1988, 1992; Goericke and Repeta, 1992). Two genetically and physiologically distinct ecotypes have been recognized that have implications on their ecological distribution. High-B/A (previously designated as low-light adapted) isolates have larger ratios of Chl b/a_2 and are able to grow in extremely low radiances where low-B/A isolates (previously designated as high-light adapted strains) are incapable of growth. Low-B/A isolates have lower Chl b/a_2 ratios and are able to grow maximally at higher light intensities where high-B/A isolates are inhibited (Moore and Chisholm, 1999). On the basis of 16S rDNA sequences strains of low-B/A ecotype are very closely related to each other (with 99% identity supported by bootstrap values; Urbach *et al.*, 1998; Moore and Chisholm, 1998; Rocap *et al.*, 1999). At the same time strains of high-B/A ecotypes have a lower degree of identity in their 16S rDNA sequence (97 to 98%) and are not monophyletic but at least form three independent branches (Rocap *et al.*, 1999). These also exhibit a high degree of sequence similarity to the *Synechococcus* strains of MC-A.

The resolution of *Prochlorococcus*-*Synechococcus* by 16S rRNA-23S rRNA ITS regions: Rocap *et al.* (2002) resolved *Prochlorococcus* and *Synechococcus* ecotypes on the basis of 16S rRNA-23S rRNA ITS sequence homology. They have examined 32 *Prochlorococcus* strains and 25 *Synechococcus* isolates from all over the world. These exhibited a variation in length and G+C content of the spacer. All of them uniformly possessed tRNA^{Leu} and tRNA^{Ala} genes. The results further justify the recognition of high-B/A and low-B/A strains of *Prochlorococcus* and six clades of MC-A of *Synechococcus*. Interestingly, three of them are associated with a particular phenotype (motility, chromatic adaptation and lack of phycourobilin).

The diversity of marine *Synechococcus* strains occurring in Chesapeake Bay has been determined by 16S rRNA-23S rRNA ITS sequences (Chen *et al.*, 2006). A phylogenetic analysis of 82 picocyanobacterial ITS sequences revealed that the majority of the sequences were affiliated with either MC-A or MC-B. Among the 22 environmental clones isolated from Chesapeake Bay (CB) waters, 13 of them clustered with MC-A while the rest 9 clustered with MC-B. They further identified 16 sub-clusters (having more than 95% sequence identity) with a bootstrap value of 100 in MC-B. Eleven of these sub-clusters overlapped with those already reported in literature (Rocap *et al.*, 2002; Ernst *et al.*, 2003) whereas five subclusters (CB1 to CB5) have been considered to be novel and unique to Chesapeake Bay. Of these, at least two subclusters (CB4 and CB5) could be defined. The subcluster CB-4 consisted of five PE-rich *Synechococcus* strains (CB0206, CB0207, CB0208, CB 0209 and CB0210) that were closely related to PC-rich *Synechococcus* strains (CB0101, CB0102, CB0202 and CB 0204). It is interesting to note that a close relationship between *Synechococcus* PE-rich and PC-rich strains has also been derived from *rbcL* phylogeny. Further the separation of MC-A and MC-B is also supported by *rbcL* phylogeny. The interoperon variation in *Synechococcus* is not problematic because of the existence of two identical rRNA operons. However, the length of heterogeneity in ITS region is sufficient to distinguish the different *Synechococcus* strains. Based on ITS phylogeny and GC content, they suggested that *Synechococcus* sp. strain WH 8007 should serve as the reference strain for MC-B but not *Synechococcus* sp. strain WH5701 as suggested earlier (Urbach *et al.*, 1998; Fuller *et al.*, 2003).

The phylogeny of *Synechococcus* strains based on 16S rRNA gene sequences revealed that this botanical form-genus is distributed into five of the eight cyanobacterial lineages (Honda *et al.*, 1999; Robertson *et al.*, 2001). Two or more strains of *Synechococcus* distributed into each of these five clusters exhibited 99.4-100% 16S rRNA sequence identity. One of these five clades is represented by picophytoplanktons in which along with PE-rich and PC-rich strains of *Synechococcus*, strains of *Prochlorococcus* have been clustered as revealed by the phylogenetic relationships drawn on the basis of 16S rRNA gene sequences as well as DNA-dependent RNA polymerase gene sequences (Palenik and Swift, 1996; Urbach *et al.*, 1998). Strains of *Synechococcus*, i.e. WH7803, PCC 7001, PCC 6307 that are representatives of oceanic, marine and freshwaters, respectively differ from one another in the length of ITS of the *rrn* operon and also differ from *P. marinus* subsp. *pastoris* PCC 9511. However, these four cyanobacteria are closely related on the basis of 16S rDNA phylogeny. A comparison of the sequences of the ITS region of these four strains with those available in the database for *Prochlorococcus* MED4 (CCMP 1378) and MIT9313 revealed that HL-adapted *Prochlorococcus* clade differed from those of LL-adapted clade by the length of ITS (Laloui *et al.*, 2002). Ernst *et al.* (2003) studied the RFLP patterns of *psbA* genes of 19 picoplanktonic cyanobacteria and the phylogenetic analysis is not consistent with the original distinction of isolates based on pigmentation. In view of this, it was concluded that selection pressure plays a great role in shaping the populations and the diversity in *Synechococcus* strains reflects ecosystem-specific adaptations. On the basis of *cpcBA*-IGS spacer region, Crosbie *et al.* (2003) showed that some closely related forms of picocyanobacteria are

widely dispersed and that the conclusions of Ernst *et al.* (2003) are quite premature and not based on appropriate population size required for sampling. They further showed the existence of at least six to seven clusters of non-marine picocyanobacteria within the picophytoplankton clade which further supports global dispersal of some closely related picocyanobacterial genotypes.

Cells of *Microcystis* are coccoid, tend to aggregate into colonies, possess gas vacuoles and are present in amorphous mucilage or circumscribed sheath. Watanabe (1996) recognized five different morpho-species (*M. aeruginosa*, *M. novacekii*, *M. ichthyoblabe*, *M. viridis* and *M. wesenbergii*) from within the bloom-forming species of *Microcystis* on the basis of colony, sheath characteristics and the mode of arrangement of cells. The molecular and chemotaxonomic data point out that each of these five morphospecies is non-monophyletic and is quite similar genetically and biochemically. Otsuka *et al.* (2001) proposed that these five morphospecies should be merged into one species i.e. *M. aeruginosa*. A number of attempts have been made to distinguish toxic strains of *M. aeruginosa* from the non-toxic ones. These are based on 16S rRNA gene sequencing (Neilan *et al.*, 1997; Lyra *et al.*, 2001; Tillett *et al.*, 2001), 16S rRNA-23S rRNA ITS sequencing (Otsuka *et al.*, 1999; Janse *et al.*, 2003), *cpcBA*-IGS sequences (Neilan *et al.*, 1995; Tillett *et al.*, 2001) and the microcystin (*mcy*) gene, (Nishizawa *et al.*, 1999; Tillett *et al.*, 2001; Kurmayer *et al.*, 2002). These observations point towards the absence of any relationship between genetic similarity and toxicity of a strain. This is more evident when *mcy* was chosen as a marker for distinguishing between the toxic and non-toxic strains where it was revealed that a single *mcy* genotype consisted of both toxic and non-toxic strains. To overcome these inconsistencies, Tanabe *et al.* (2007) adopted MLST approach for phylogenetic analysis of *Microcystis* based on seven housekeeping genes such as *ftsZ* (governing cell division protein FtsZ), *glnA* (glutamine synthetase), *gltx* (glutamyl-tRNA synthetase), *gyrB* (DNA gyrase subunit B), *pgi* (glucose-6-phosphate isomerase), *recA* (encodes recombination protein RecA) and *tpi* (triose phosphate isomerase). Phylogenetic trees constructed on the basis of NJ method revealed five clusters of *Microcystis*. Cluster A consisted of toxic strains, Cluster B had both toxic as well as non-toxic strains, Cluster C, Cluster D and Cluster E possessed non-toxic strains but with the exception of Cluster D where the strains possessed *mcyG* gene.

Based on the morphological criteria, ten species recognized in Europe [*M. aeruginosa* (Kützing) Kützing, *M. viridis* (A. Braun in Rabenhorst) Lammermann, *M. wesenbergii* Komárek in Konratieva, *M. novacekii* (Komárek) Compère, *M. ichthyoblabe* (Kützing), *M. flos-aquae* (Wittrock) Kirchner, *M. natans* (Lammermann) ex Skuja, *M. firma* (Kützing) Schmidle, *M. smithii* (Kützing et Anagnostidis) and *M. botrys* (Teiling)] are resolved by 16S rRNA gene sequences with less than 1% divergence (Otsuka *et al.*, 1998; Boyer *et al.*, 2001). Phylogenetic trees of the strains in the genus *Microcystis* based on direct sequencing of 16S rRNA-23S rRNA ITS region did not match with the morphological characteristics defined for delineating the various species (Otsuka *et al.*, 1999). In view of this, El Herry *et al.* (2008) coined the term 'morphospecies' instead of species. The RFLP patterns of the 16S-23S rDNA ITS regions of morphospecies of *Microcystis* (MCYS-LB01, MCYS-LB02 and LB03) isolated from Lebna Dam in Tunisia exhibited a similar pattern suggesting that they represent intraspecific variations or phenotypic variations but did not agree with previous assignments made in respect of MCYS-LB01 and LB02 to *M. aeruginosa* or MCYS-LB03 to *M. wesenbergii*.

iii) Freshwater *Leptolyngbya* lineage (V lineage according to Wilmotte and Herdman, 2001): The genus *Leptolyngbya* was created by Anagnostidis and Komárek (1988) to include a large number of *Oscillatoria* spp. with trichomes up to 3 µm. Some of these strains have been included in LPP-group B by Rippka *et al.* (1979). *Leptolyngbya foveolarum* Komárek 1964/112 and *L. boryanum* PCC 73110 that cluster here share morphological and 16S rRNA gene sequence identity. In addition to *L. foveolarum*

Komárek 1964/112 and *L. boryanum* PCC 73110, Nelissen *et al.* (1996) also described the presence of *Oscillatoria amphigranulata* CCCNZ-Concert-Oa-1, *Leptolyngbya minutum* D5 and the marine strains *L. ectocarpi* PCC 7375, *L. ectocarpi* N 182 and *L. ectocarpi* CCAP 1462/5 in this cluster but poorly supported by bootstrap values. However, *L. foveolarum* Komárek 1964/112 and *L. boryanum* PCC 73110 showed 99.5% 16S rDNA sequence similarity with 100% bootstrap support. On the basis of phylogenetic analysis, Nelissen *et al.* (1996) are of the opinion that *O. amphigranulata* CCCNZ-Concert-Oa-1 should be assigned to the genus *Leptolyngbya* despite the fact that *O. amphigranulata* Van Goor was assigned to the genus *Limnothrix* by Anagnostidis and Komárek (1988). Castenholz (1992) suggested that the morphological descriptions of *O. amphigranulata* CCCNZ-Concert-Oa-1 and *O. amphigranulata* Van Goor are different and that the latter should be assigned to a new genus and species altogether. The 16S rRNA gene sequences of *Phormidium* M-99 and *Oscillatoria* M-117 are shown to be identical to those of this lineage but Ishida *et al.* (1997) have not documented the morphological identification for these strains.

A polyphasic taxonomic approach has been undertaken to resolve 75 strains of Oscillatoriid cyanobacteria by taking into consideration morphological characters, growth temperature, salinity tolerance, complementary chromatic adaptation (CCA), DNA base composition and 16S rDNA analysis. Six groups have been identified on the basis of 16S rDNA sequencing, all of which are clearly separated from the type species *Oscillatoria princeps* Gomont NIVA CYA 150. That is why Suda *et al.* (2002) recommended that these strains should be classified into separate genera other than *Oscillatoria*. Groups I-III are closely related to each other and Groups IV-VI are distinct from one another and from Groups I-III. Group I is subdivided into strains producing PC (Group I-pc) and PE in addition to PC (Group I-pe). The mol% G+C content of Groups I and II is 39.5 ± 0.4 and 39.5 ± 0.2 respectively whereas Group III showed a mol% G+C of 40.0 ± 0.2 . A slightly higher mol% G+C of 44.0 ± 0.4 and 44.0 ± 0.6 is found in Groups IV and V, respectively. The similarity of 1361 bp region of 16S rDNA is in the range of 95.4–96.8% for Groups I-III and fatty acid composition of these strains is similar. Strains of Group IV exhibited a similarity of 89.7% and the fatty acid composition of this group is different. These results are supported by DNA:DNA hybridization studies.. Group I consisted of 58 strains with a RB value of 99.2%. Groups II and III were represented by 5 and 4 strains with RB values at 98.4% and 99.8%, respectively. Group IV was represented by 6 strains and these within each other exhibited an RB value of 99.1%. Groups V and VI are represented by one strain each with RB values of 91.9% and 86.4%, respectively with other groups. On the basis of overall assessment, strains of group I-pc have been treated as *Planktothrix agardhii* and those of group I-pe as *Planktothrix rubescens*. They also considered it appropriate to treat *O. mougeotii* Kützing ex Forti as a synonym of *P. rubescens* (*O. rubescens*). Amended or new taxonomic descriptions (for the subgroups and groups) for *P. agardhii* (type strain NIES 204^T), *P. rubescens* (type strain CCAP 1459/22^T), *Planktothrix pseudoagardhii* sp. nov. (type strain T 1-8-4^T), *Planktothrix mougeotii* (type strain TR1-5^T), *Planktothricoides raciborskii* gen nov.comb. nov. (type strain NIES 207^T), *Tychonema bourrellyi* (type strain CCAP 1459/11B^T) and *Limnothrix redekei* (type strain NIVA CYA 277/1^T) have been presented.

The studies of Thacker and Paul (2004) on morphological, chemical and genetic diversity of *Lyngbya* spp. and *Symploca* spp. revealed that 16S rDNA sequence analysis though strongly supported monophyly of *Lyngbya* and *Symploca* as well as monophyly of *L. bouillonii* and *L. majuscula* but it does not explain the chemical variability among the *Lyngbya* species.

(iv) *Pseudoanabaena* cluster (VI lineage according to Wilmotte and Herdman, 2001): In most of the strains of *Pseudoanabaena* the trichomes are less than 4 µm width with cells longer than broad and possess constricted cross walls (Castenholz, 2001; Komárek, 2003). Some of the strains exhibit

CCA by regulating the levels of PC and PE according to the available spectrum of light. The presence of gliding motion and the ability to fix atmospheric nitrogen are the other traits exhibited by some other strains of this genus. Due to the closer resemblances of *Pseudoanabaena* spp. with those of *Limnothrix* as well as their occurrence together makes their identification slightly difficult. Acinas *et al.* (2009) conducted a phylogenetic study of 28 *Pseudoanabaena* strains from Baltic Sea (BS) and the Albufera de Valencia (AV) on the basis of sequencing of 16S rRNA and 23S rRNA genes, their *ITS1* region, the *cpcBA* operon, the *IGS* between *cpcA* and *cpcB* and the *nifH*. These studies revealed the existence of specific clusters for strains from BS and AV and a third cluster contained a mixture of strains from both the geographical regions that exhibited CCA. Although the analyses from 16S rRNA and 23S rRNA genes are consistent but the analyses from other loci indicated extensive genetic recombination between strains. 16S rDNA analysis revealed clustering of certain *Pseudoanabaena* with strains of *Limnothrix* including *L. redekei*. These observations are consistent with the earlier findings of Wilmotte and Herdman (2001). This cluster is commonly called as *Pseudoanabaena*/*Limnothrix* group. Several environmental sequences as well as other isolates including the type strain *Pseudoanabaena* PCC 7408 and several strains of *Limnothrix* from Lake Loosdrecht along with *Limnothrix redekei* CCAP 1443/1 and *Limnothrix redekei* CCAP 227/1 are members of this lineage.

v) *Trichodesmium*-*Oscillatoria* PCC 7515 lineage (XII lineage according to Wilmotte and Herdman, 2001): So far five species of *Trichodesmium* have been described (Wille, 1904; Sournia, 1968) and these have been further confirmed by both morphological as well as ultrastructural features. These five species of *Trichodesmium* are, *T. thiebautii*, *T. erythraeum*, *T. tenue*, *T. contortum*, and *T. hildebrandtii* (Janson, 1995). There is very low genetic diversity amongst these strains as revealed by molecular approaches of sequence analysis of *nifH*, *hetR*, and 16S rRNA (Carpenter, 1983; Zehr *et al.*, 1990; Ben-Porath *et al.*, 1993). Wilmotte *et al.* (1994) showed that *Trichodesmium* sp. strain NIBB 1067 is closely related to *Oscillatoria sancta* PCC 7515 showing 94.9% 16S rRNA gene sequence similarity. Genes encoding tRNA^{Ile} and tRNA^{Ala} are present in the 16S rRNA-23S rRNA ITS region of *Trichodesmium*. On the basis of 16S rDNA and *hetR* sequences, Janson *et al.* (1999) were able to resolve three clades in *Trichodesmium* containing (i) *T. thiebautii* and *T. hildebrandtii*, (ii) *T. contortum* and *T. tenue*, and (iii) *T. erythraeum*. However, the *hetR* sequencing provided a better resolution between the species *T. erythraeum* and *T. thiebautii* than analysis of the 16S rDNA region gave. Orcutt *et al.* (2002) investigated the genetic diversity of *Trichodesmium* spp. by using three independent techniques that provide high resolution. A PCR-based DNA fingerprinting method using base pair extended short oligonucleotide primers for HIP1 was used to distinguish *Trichodesmium* spp. This technique was used to distinguish a number of strains of cyanobacteria (Robinson *et al.*, 1995; Smith *et al.*, 1998). Further, DGGE analysis of a fragment of *hetR* gene and the sequencing of 16S rRNA-23S rRNA ITS region were also conducted to reveal the genetic diversity in this genus. Natural populations of *Trichodesmium* spp. (from Bermuda in the Sargasso Sea and North Australia in the Arafura and Coral Seas) and some culture isolates (from Sargasso Sea and the Indian Ocean) were subjected to diversity studies by employing the above three methods. Although a remarkable similarity existed in between cultures of *T. thiebautii*, *T. hildebrandtii*, *T. tenue* and *Katagnymene spiralis*, low genetic diversity was revealed in the strains from the two hemispheres. Two major clades are recognized and largest genetic variation was found in between the strains of *T. erythraeum* (Orcutt *et al.*, 2002).

vi) *Geitlerinema* lineage (XIV cluster according to Wilmotte and Herdman, 2001): Bittencourt-Oliveira *et al.* (2009) conducted a phylogenetic study of ten strains of *Geitlerinema* [six of *Geitlerinema amphibium* (C. Agardh ex Gomont) Anag. and four of *Geitlerinema unigranulatum* (Rama N. Singh) Komárek et M.T.P. Azevedo] on the basis of PC-IGS sequencing. Two strains (*G. unigranulatum*

BBCUSP 352 and *G. unigranulatum* BBCUSP 94) have been found to be distinct from all others despite their morphological similarity. These two strains could be assigned to a different species of *Geitlerinema*. However, on the basis of morphological features, cell ultrastructure and *PC-IGS* sequences, *G. amphibium* and *G. unigranulatum* are indistinguishable and so can be merged into a single species (Figs. 18, 19 and 20). Phylogenetic trees constructed by MP, NJ, ML and Bayesian analyses revealed similar pattern in the clades as well as the clades remained the same by the rooted and unrooted trees.

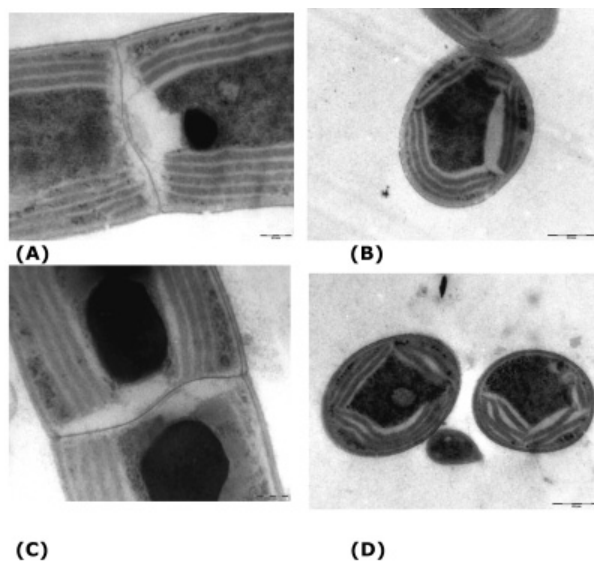


Figure 18: Electron micrographs of *Geitlerinema amphibium* longitudinal and cross sections of strains BCCUSP91 (A and B) and BCCUSP85 (C and D), respectively. Scale bar 500 nm. Photographs courtesy M. D. C. Bittencourt-Oliveira, Department of Biological Sciences, Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba 13418-900, SP, Brazil.

PCR and DGGE analysis in cyanobacteria

Any gene sequence that shows considerable sequence heterogeneity can be chosen as a molecular marker for assessing the microbial diversity through this method. DGGE analysis of 16S rRNA gene segment of cyanobacterial populations has been done (Nübel *et al.*, 1997; Garcia-Pichel, 2000; Abed and Garcia-Pichel, 2001). Due to the fact that 16S rRNA gene falls short of resolving differences between closely related organisms, a number of workers consider 16S rRNA-23S rRNA ITS region to be very suitable for high resolution analysis because of greater degree of sequence heterogeneity and the availability of published rRNA-ITS sequences. DGGE has been used for analysis of *Synechococcus* (Becker *et al.*, 2002) and *Aphanizomenon* (Laamanen *et al.*, 2002) strains on the basis of 16S rRNA-23S rRNA ITS sequences. Amplification of *ITSa* region gave rise to one sharp band occupying an unique position in the gel in all the cyanobacteria studied. However, only *Aph. gracile* yielded two bands. The amplification products of *ITSb* and *ITSc* regions that were longer when subjected to DGGE gave rise to one (in case of *Synechococcus*, *Synechocystis*, *Lyngbya*, *Pseudoanabaena*, *Trichodesmium* and *Prochlorothrix*), two (in case of *Leptolyngbya*) and two to four bands (in case of most of the strains

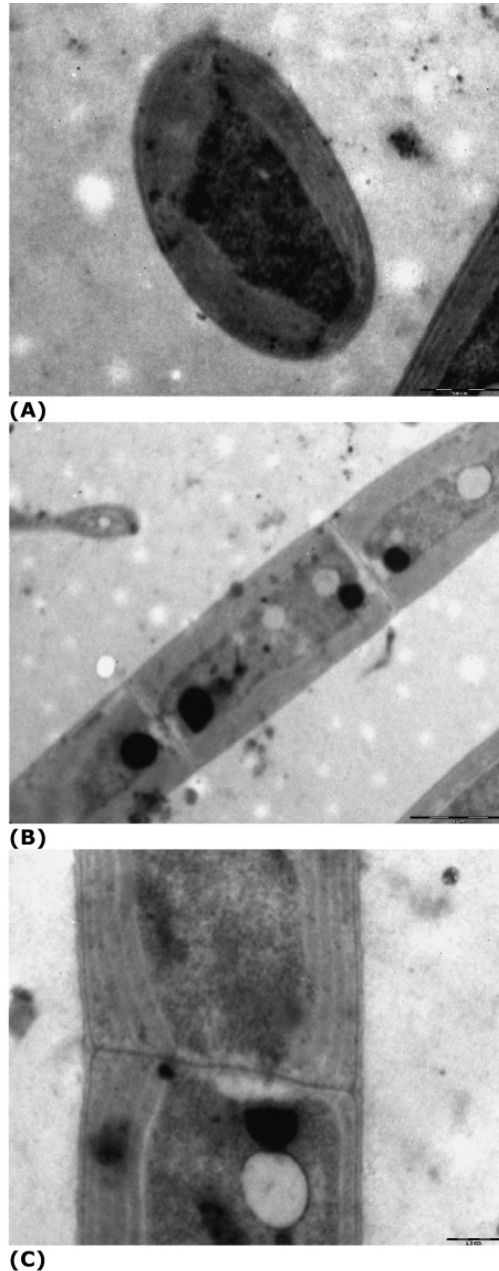


Figure 19: Electron micrographs of *G. unigranulatum* BCCUSP352 strain cross (A) and longitudinal sections (B and C). Scale bar 500 nm. Photographs courtesy M. D. C. Bittencourt-Oliveira, Department of Biological Sciences, Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba 13418-900, SP, Brazil.

from genera *Anabaena*, *Aphanizomenon*, *Planktothrix*, *Cylindrospermopsis* and *Gloeotrichia*) (Janse *et al.*, 2003). DGGE of *hetR* gene for resolving the differences in between strains of *Trichodesmium* and *Nostoc* (Palinska *et al.*, 1996; Orcutt *et al.*, 2002) and *nifH* for determining the diversity of nitrogen-fixing

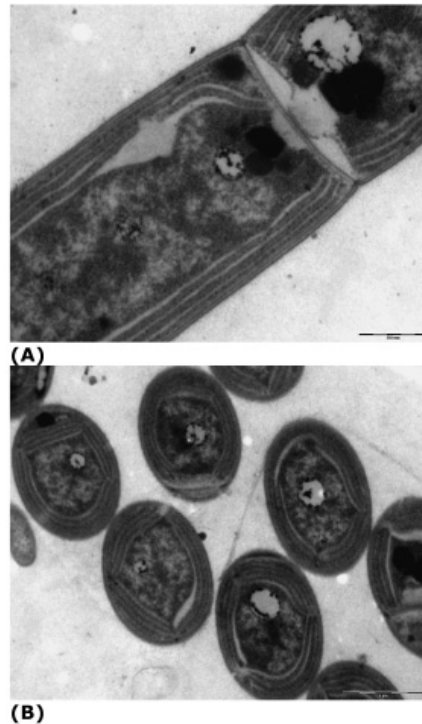


Figure 20: Electron micrographs of *G. unigranulatum* BCCUSP47 strain longitudinal (A) and cross sections (B). Scale bar 500 nm. Photographs courtesy M. D. C. Bittencourt-Oliveira, Department of Biological Sciences, Luiz de Queiroz College of Agriculture, University of São Paulo, Piracicaba 13418-900, SP, Brazil.

organisms (Lovell *et al.*, 2001) have been employed. Berrendero *et al.* (2008) compared phylogenetic relationships based on 16S rRNA gene sequences with the variability in PC operon and the intervening spacer sequence (*cpcBA-IGS*) between strains of *Rivularia* and *Calothrix* by temperature-dependent DGGE. The high variability of the PC-IGS among the genotypes was not consistent with the morphologies observed. However, the phylogenetic relationship drawn in case of *cpcBA-IGS* is largely consistent with 16S rRNA gene sequences.

Phylogenetic analysis based on the sequences of the nitrogen-fixing gene *nifD* from a number of representatives of subsection IV and subsection V reflected the monophyly of the heterocystous cyanobacteria. Neither of these subsections is monophyletic because of intermixing of the strains with two sister clades. Clade I is composed of two smaller branches Clade 1a and Clade 1b. Clade 1a consisted of representatives of *Calothrix* (IV.II; strain PCC 7102), *Scytonema* (IV.I; PCC 7814 and PCC 7110), *Fischerella* (V; strains PCC 7603, PCC 7414, PCC 1903) and *Chlorogloeopsis* (V; strain PCC 6718) and Clade 1b was represented by *Nostoc* (IV.I; strains PCC 7120, PCC 6720, PCC 7423), *Cylindrospermum* (IV.I; PCC 7604) and *Chlorogloeopsis* (V; PCC 6912). Clade 2 is composed of strains of *Calothrix*, *Nostoc*, *Anabaena* (IV.I), *Nodularia* (IV.I), *Cylindrospermum* and *Tolypothrix* (IV.II). Intermingling of strains of *Calothrix* (PCC 7507) with those of *Nostoc commune* UTEX 584 and sister *Anabaena* strains (PCC 7122, PCC 7108 and ATCC 33047) has been noted in Clade 2. The MP and NJ trees were virtually identical to ML tree (Henson *et al.*, 2004).

4) Diversity of cyanobacteria determined on the basis of molecular markers: During recent years, diversity studies of cyanobacteria based on sequencing of 16S rRNA, 16S rRNA-23S rRNA ITS region, ARDRA, T-RFLP and PCR with DGGE techniques have been made circumventing the collection-and culture-based studies (i.e. metagenomic analysis). In some of the cases, the molecular taxonomic data have been correlated with the cultures of cyanobacteria raised from the same habitats. Some of these are summarized here.

The molecular techniques described above play a meaningful role in assessing the diversity of cyanobacteria from a wide variety of ecosystems (Kumari *et al.*, 2009). These require the extraction of nucleic acids and do not allow the identification of individual cells from the environmental samples. However, the identification of whole fixed cells by *in situ* hybridization with rRNA targeted oligonucleotide probes has been advocated (Amann *et al.*, 1995). This technique is so powerful that cyanobacteria in deeper layers of microbial mats can be identified. One disadvantage is that the autofluorescence exhibited by cyanobacterial cells due to the presence of chlorophyll disrupts the fluorescence label associated with oligonucleotide probes upon hybridization within the target cells. To overcome this problem, Schönhuber *et al.* (1999) developed a non-fluorescent assay method, based on horseradish peroxidase (HRP)-labelled oligonucleotides, for identification of cyanobacterial cultures as well as cyanobacteria existing in microbial mats. With the help of cyanobacteria-specific primers designed by them (CYA 361, CYA 664, CYA 762, CIV/V 1342 together with EUB 338 that targets most bacteria) and dot blot hybridization, the cells can be detected by the formation of a coloured precipitate by oxidative polymerization of the non-fluorescent substrate diaminobenzidine. Additionally, they also evaluated the automatic fluorescence detection system based on enzymatic signal amplification (Schönhuber *et al.*, 1997; Van Gijlswijk *et al.*, 1996). This is known as tyramide signal amplification (TSA) system that involves covalent binding of fluorochrome tyramide substrate molecules to electron rich moieties such as tyrosine and tryptophan in the HRP-containing cells. It was possible to identify *in situ* cyanobacterial diversity from microbial mats from alpine lake in Switzerland. According to these workers, this method complements the traditional methods based on phenotype and the identification of cyanobacteria will be more reliable. Another approach, suggested to overcome the problem of autofluorescence of the cells, is to hybridize with biotin-labelled probes and allow reaction with a streptavidin-HRP conjugate, prior to detection employing TSA. This has successfully been done in case of bacteria (Lebaron *et al.*, 1997). With the help of probe CYA664 (5'-GGAATTCCTCTGCCCC-3') that targets all known marine species of *Synechococcus* and *Prochlorococcus* and in combination with TSA, closely related *Prochlorococcus* genotypes belonging to HL-adapted and LL- adapted were shown to be distributed at different depths of North Atlantic Ocean and the Red Sea. While LL-adapted strains are distributed in deeper layers in both these waters, the HL-adapted *Prochlorococcus* populations not only exhibited distinct distribution patterns for each region but also are distributed at different depths (West *et al.*, 2001). However, the cell fixation step and permeabilization of cells using alcohol and/or detergents used in these studies prior to hybridization with labelled 16S rRNA-targeted probe sometimes damages the cells. This is especially true for *Prochlorococcus* or *Synechococcus* cells from oceanic samples. In light of this, another method promising in the analysis of individual cells is whole-cell hybridization with fluorescently labelled rRNA-targeted oligonucleotide probes combined with flow cytometry (Amann *et al.*, 1990). This has been successfully achieved to quantify individual cells from cultures of *Synechococcus* (Chisholm, 1992). A relationship between the rRNA content of *Synechococcus* cells and growth rate has been demonstrated by Binder and Liu (1998). At slow growth rates, the rRNA content almost remained constant but at intermediate growth rates the rRNA content per cell increased proportionally with growth rate and a corresponding decrease in its content was noted at saturating light intensities

(Binder and Liu, 1998). So this method would be ideally suited for estimating the growth rates of such organisms *in situ* as well. Another approach for *in situ* identification is the use of peptide-nucleic acid (PNA) probes. PNA possesses a homomorphous pseudopeptide backbone instead of sugarphosphate backbone of DNA (Egholm *et al.*, 1993; Sen and Nilsson, 1998). The hybridization product of PNA and RNA exhibits higher thermal stability than the DNA-RNA duplex. Due to this inherent advantage, Worden *et al.* (2000) used PNA probes to detect rRNA in intact cells of *Prochlorococcus* and *Synechococcus* in combination with flow cytometry. It would thus be easier to detect these cells in mixed microbial communities during field studies.

Rudi *et al.* (2000) employed oligonucleotide labelled probes targeting 16S rDNA followed by hybridization of these probes to their respective complements spotted on to a solid support (DNA array). With the help of 10 such species-specific probes developed, it was possible to identify relative abundance of cyanobacteria occurring in mesotrophic and eutrophic lakes. There was a good correlation between the diversity of cyanobacterial species determined as per traditional taxonomy and by molecular methods of analysis. Likewise, Wilson *et al.* (2000) designed species-specific primers for the amplification of a 609-bp region of *rpoC1* gene by PCR from 19 cultured isolates of *C. raciborskii*. Sequence analysis revealed that all isolates belonged to the same species. Further, RAPD and STRR sequence profiles revealed a greater heterogeneity among *C. raciborskii* strains. The identification of *C. raciborskii* alone from purified DNA samples as well as environmental samples was quite possible by the amplification of specific region of *rpoC1* gene. This would be greatly helpful in the identification of this toxin-producing cyanobacterium from natural waters. Abed *et al.* (2002a) studied the diversity of benthic cyanobacterial mats inhabiting polluted waters of Wadi Gaza (Gaza Strip, Palestine) and monitored community changes of these mats in the laboratory consequent upon degradation of petroleum compounds. PCR amplified products of 16S rRNA gene, with cyanobacteria-specific primers CYA 359F (with 40 nucleotide clamp at 5'-end) and CYA 781R, were subjected to DGGE at 60 °C. DNA from these bands was sequenced, aligned and phylogenetic tree construction made by different methods in the ARB software. *Phormidium* and *Oscillatoria*-like cyanobacterial morphotypes dominated the polluted habitats and the *in vitro* samples were dominated by a *Phormidium*-like new cyanobacterium named as *Halomicronema*. Samples collected from microbial mats, maintained in artificial ponds in Eilat (Israel), when subjected to DGGE also revealed the existence of *Halomicronema* in large numbers. By adopting a polyphasic taxonomic approach (morphology, ultrastructure, 16S rRNA-based phylogeny, temperature and salinity physiology and chemotaxonomic markers like the presence of special carotenoids and mycosporine-like amino acids) *Halomicronema excentricum* *gen. et sp. nov.* has further been characterized (Abed *et al.*, 2002b).

Taton *et al.* (2003) presented cyanobacterial diversity patterns in natural and artificial microbial mats of Lake Fryxell (McMurdo Dry Valleys, Antarctica) on the basis of morphological and molecular methods. DNA isolated from environmental samples was subjected to ARDRA analysis after PCR amplification of 16S rDNA and fragments of 422 bp long generated by seminested PCR have been subjected to DGGE, followed by sequencing. They have identified 16S rRNA-23S rRNA ITS sequences from environmental samples for the first time. Molecular diversity appeared to be more than microscopic diversity. Phylogenetic analysis revealed 11 lineages of which 3 have been found to be exclusive to Antarctica and two of these were found to be novel. Microscopy revealed 8 morphotypes (*Nostoc*, *Nodularia* cf. *harveyana*, *Oscillatoria* cf. *subproboscidea*, *Phormidium* cf. *autumnale*, *Schizothrix* sp., *Leptolyngbya* 1 and *Leptolyngbya* 2 with rare presence of *Hydrocoryne* cf. *spongiosa* and *Phormidium* cf. *autumnale*). *Phormidium* cf. *autumnale* has been observed as a minor component of microbial mats *in vivo* but dominated *in vitro* with the absence of other heterocystous members like

Nodularia cf. *harveyana* and *Hydrocoryne* cf. *spongiosa*. Jungblut *et al.* (2005) studied the diversity of cyanobacterial mat communities from meltwater ponds with variable salinities located at McMurdo Ice Shelf, Antarctica. Callejas *et al.* (2010) presented ARDRA analysis of benthic cyanobacterial mat community from King George Island, Antarctica leading to the identification 16S rRNA genes similar to those of *T. bourrellyi* and *T. bornetii* for the first time. These accounted for 9.4% of the total clones whereas 7.6% clones of the PCR amplified 16S rRNA gene library resembled the phylotypes described earlier from Lake Fryxell (Taton *et al.*, 2003) and McMurdo Ice Shelf, Antarctica (Jungblut *et al.*, 2005).

Cyanobacterial ecotypic diversity of microbial mats, growing in a hot spring at 68°C, has been determined by 16S rRNA-23S rRNA gene sequence analysis. The existence of physiologically distinct populations of *Synechococcus*, adapted to differing light conditions, is a characteristic feature of these microbial mats (Ferris *et al.*, 2003). Blackband disease (BBD) is a disease of corals that occurs worldwide and is caused by sulfide-rich microbial mat dominated by filamentous cyanobacteria. The identity of these organisms was traced by cloning and sequencing of 16S rRNA gene using universal primers. Myers *et al.* (2007) identified four isolates of *Geitlerinema* and three related to the genus *Leptolyngbya*. However, DGGE of 26 BBD samples using cyanobacteria-specific primers revealed that the most common representative is a species of *Oscillatoria*. The cultures showed the property of sulfide-resistant oxygenic photosynthesis and the production of the toxin microcystin as the root cause of the disease.

The distribution of unicellular diazotrophic cyanobacteria along a transect of Arabian Sea has been studied by PCR amplification of 16S rRNA gene by employing an oligonucleotide primer, NITRO 821R specific for unicellular diazotrophs in combination with cyanobacteria-plastid specific forward primer CYA 359F. The distribution patterns suggested that the organisms were preferentially located in warm oligotrophic subsurface waters and temperature appeared to be the key factor governing their distribution (Mazard *et al.*, 2004).

Song *et al.* (2005) studied the biodiversity and seasonal variation of cyanobacterial assemblages in paddy fields in Fujian, China by a semi-nested PCR, followed by DGGE analysis. The 24 cyanobacterial phylotypes observed varied with the season and growth phase of rice crop. Sompong *et al.* (2008) determined cyanobacterial diversity from six hot springs of Thailand by extracting DNA, and the 16S rRNA genes were identified by PCR amplification by employing CYA 359F and CYA 781R primers and separated the DNA by subjecting to DGGE with 7M urea and 10% V/V formamide as denaturants. Thirty eight distinct bands were reamplified and sequenced. They were able to identify *Oscillatoria* lineage (O1), *Phormidium* lineage (P1), *Synechococcus* lineage (S3), *Oscillatoria* lineage (O2), *Synechococcus* lineage (S2), *Synechococcus* lineage (S1) and *Phormidium* lineage (P2). A comparative survey of cyanobacterial flora has been conducted by light microscopy and PCR-DGGE of 16S rRNA gene of the cyanobacterial flora from rice fields in eastern Uttar Pradesh by Srivastava *et al.* (2009). The diversity of cyanobacteria as revealed by light microscopic identifications based on traditional taxonomy (Fig. 21) corresponded with the observations on PCR-DGGE. From a total of 51 bands selected for sequencing only 31 DGGE bands proved to be significant for phylogenetic analysis. NJ method of analysis conducted revealed the existence of 6 clades. The distribution of cyanobacteria appeared to depend on the salinity of soils. Of the six clades, Clade 1 is represented by filamentous, heterocystous cyanobacteria such as *Anabaena*, *Nostoc*, *Gloeotrichia* and *Cylindrospermum*. Clade 2 is composed of branched members like *Hapalosiphon* and *Fischerella*. Clade 3 consisted of cyanobacteria from normal soils. Clade 4 is composed of *Aulosira*, *Phormidium*, *Lyngbya* with occasional presence of *Anabaena oryzae* and *A. anomala*. Clade 5 is represented by *Oscillatoria* and *Gloeotheca* from saline soils while the distribution of *Aulosira*, *Nostoc*, *Anabaena* and *Hapalosiphon* depended over a wide

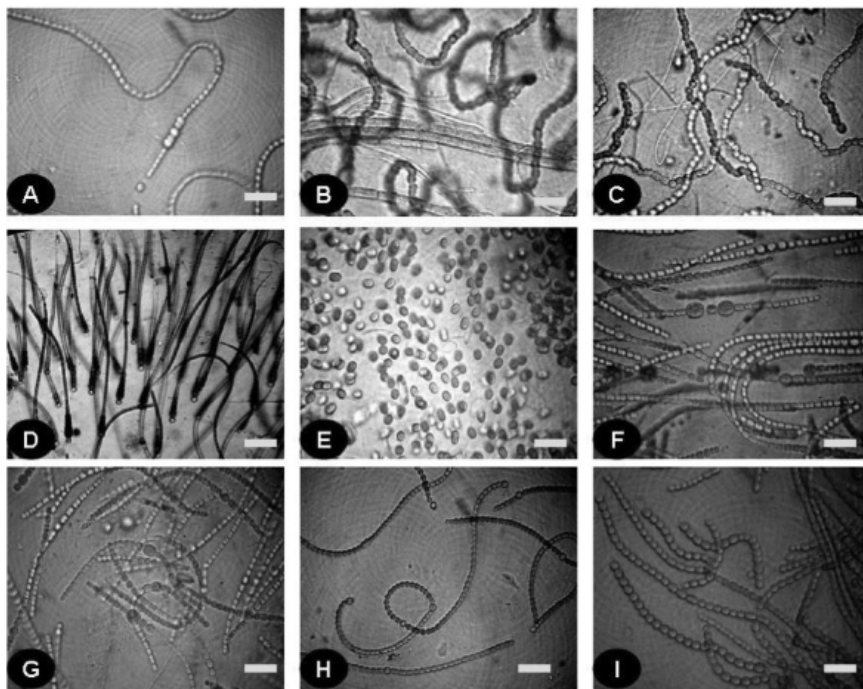


Figure 21: Community of cyanobacteria collected from different rice fields as seen in microscope (resolution 40×). Some of the cyanobacterial genera that constituted the community were *Anabaena* (A, C and F), *Aulosira* (B), *Gloeotrichia* (D), *Aphanothece* (E), *Nostoc* (G and H) and *Hapalosiphon* (I). Bars, 10 µm. With the kind permission of L. C. Rai, Center of Advanced Study in Botany, Banaras Hindu University, Varanasi-221005, India and B. A. Neilan, School of Biotechnology and Biomolecular Science, The University of New South Wales, Sydney, NSW 2052, Australia. [Srivastava *et al.* (2009) *Saline systems* 5: 4; doi :10.1186/1746-1448.5-4].

range of salinities. The diversity of marine picocyanobacteria (*Prochlorococcus* and *Synechococcus*) as assessed by DGGE and T-RFLP of 16S-23S rRNA ITS region revealed the presence of more than one band or T-RF per strain or cloned sequence suggesting the existence of anomalies due to the formation of secondary structures. Modelling of ITS structures at different temperatures of PCR revealed the presence of hairpin loops. So accordingly, Lavin *et al.* (2008) modified T-RFLP method by the addition of labelled ITS primer in the last two cycles of the PCR that resulted in most cases only one T-RF per ribotype. Natural picophytoplanktonic communities in marine waters of Chile showed that it is possible to identify several phylogenetic lineages within the genera *Prochlorococcus* and *Synechococcus*. This study shows that T-RFLP with the proposed modification is suitable for studying diversity of natural populations of cyanobacteria.

The assessment of genetic diversity of geographically unrelated *M. aeruginosa* strains using AFLP has been made by Oberholster *et al.* (2005). Phylogenetic analysis of AFLP polymorphisms of 23 strains of *Microcystis* revealed the existence of four clusters. Cluster 1 is composed of *Microcystis* strains (NIES) from Japan whereas Cluster 2 is represented by European strains. South African strains (from northern parts) formed a group in Cluster 3 and Cluster 4 consisted of strains from central and southern parts of South Africa along with strains from USA. The superior discriminative

power of this technique in the differentiation of different genotypes of *Microcystis* has been stressed. Floyd *et al.* (2005) analysed the holdings of prokaryotes at the American Type Culture Collection (ATCC) with regard to the geographical and environmental habitats from which they were isolated. A comparison of the selected habitats in the recently published literature on culture-independent assays on microbial diversity revealed as to how the cultured members existing in ATCC are distributed in nature. Of the 37 environmental habitats, isolates from soil were maximum (27.3%), followed by those from host-associated, terrestrial, plant (16.0%) and lastly from food and food-processing associated (7.3%) habitats. The origin of nearly 41.4% of the cultures (2,209 entries) is not known. Isolates from N. America were 24.1% (1289 entries) followed by those from Europe (14.7% and 784 entries) and lastly from Asia (11.5% and 612 entries). A comparison of the number of known microbial species in biodiversity hotspots from various continents revealed maximum number of species (314) from Europe and Central Asia, followed by 138 microbial species from Mainland Asia (Indo-Burma region of hotspot). Microcystin synthetase (*mcy A* gene) was chosen as the molecular marker for the quantification of toxic cyanobacteria from polluted waters with the help of a novel primer MSR-2R by conducting a real-time PCR. A direct correlation existed between the number of cells in the culture and those determined by PCR. The detection limit has been found to be 8.8 cells per reaction. The gene could be successfully amplified and quantified from environmental samples (Furukawa *et al.*, 2006).

Kim *et al.* (2006) determined the cyanobacterial diversity during algal blooms in Daechung reservoir, Korea on the basis of *cpcBA*-IGS sequences from environmental samples. Sequences of *Microcystis*, *Aphanizomenon* (*Anabaena*), *Pseudoanabaena* and *Planktothrix* (*Oscillatoria*)-like groups and three other previously reported *cpcBA*-IGS sequences have been detected during the peak of bloom growth. The succession of the cyanobacteria based on *cpcBA*-IGS sequences is further supported by PCR-DGGE of 16S rRNA genes. Boutte *et al.* (2006) tested the utility of specific 16S rRNA cyanobacterial primers CYA 359F, CYA 781R(a) and CYA 781R(b) to assess molecular diversity of cyanobacteria from their natural habitats. CYA 781R(a) preferentially targeted filamentous cyanobacteria whereas CYA 781R(b) targeted unicellular cyanobacteria. Environmental *nifH* (encoding reductase subunit of nitrogenase) gene sequences from the biological soil crusts of Colorado Plateau, USA revealed the existence of three distinct clades of heterocystous cyanobacteria. These sequences matched up to nearly 89% with the *nifH* gene sequences of cultured heterocystous cyanobacteria *Nostoc commune*, *Scytonema hyalinum*, *Tolypothrix* and *Spirirestis*. These constituted the dominant members of this habitat (Yeager *et al.*, 2007).

Valério *et al.* (2009) identified 118 cyanobacterial isolates from Portuguese freshwater reservoirs belonging to Chroococcales (54), Oscillatoriales (15) and Nostocales (49). Cluster analysis of STRR and LTRR sequences, PCR fingerprinting profiles were obtained and these were subjected to molecular identification at the species level. Based on 16S rRNA and *rpoC1* phylogenies a diagnostic key for the identification of cyanobacteria based on 16S rRNA-ARDRA, ITS amplification and ITS-ARDRA has been proposed. *Planktothrix agardhii* showed lowest diversity and *Aph. flos-aquae* has the highest diversity. Prabina *et al.* (2005) has used RAPD fingerprinting as a tool for checking genetic purity of cyanobacterial strains. In most of these studies, more than ten primers were used to generate RAPD patterns. Phylogenetic analysis of 12 cyanobacterial strains belonging to Oscillatoriaceae (8 of *Oscillatoria* and 4 of *Lyngbya*) by random amplification of polymorphic DNA revealed the presence of two major clusters. One of these clusters is composed of *O. obscura* and in the second the rest of the cyanobacterial strains have clustered together (Perumal *et al.*, 2009).

5) The species concept in bacteria and cyanobacteria

As per Bergey's Manual of Systematic Bacteriology the definitions given for a bacterial genus and species are reproduced below.

Genus: "The bacterial genus is usually a well-defined group that is clearly separated from other genera, and then through descriptions of genera in the 1984 edition of Bergey's Manual exemplify the depth to which this taxonomic group is usually known. However, there is so far no general agreement on the definition of a genus in bacterial taxonomy, and considerable subjectivity is involved at the genus level. Indeed, what is perceived to be a genus by one person may be perceived as being merely a species by another systematist."

Species: "A bacterial species may be regarded as a collection of strains that share many features in common and differ considerably from other strains. One strain of a species is designated as the type strain; this strain serves as the name-bearer strain of the species and is the permanent example of the species, i.e. the reference specimen for the name. The type strain has great importance for classification at the species level, because a species consists of the type strain and all other strains that are considered to be sufficiently similar to it as to warrant inclusion with it in the species...."

A species represents a group of organisms (strains) in a taxonomic rank (Stackebrandt and Goebel 1994) and forms the basic unit of a classification system. It is a tool for describing diversity. The species name should convey about the phenotypic features of an organism and about the relationships to other organisms. We will first consider the concepts that have been developed during recent years in defining species in bacteria. Later on the species concept for cyanobacteria will be discussed. As cyanobacteria form part of phylum eubacteria, the species concept of bacteria may as well be extended to cyanobacteria. However, cyanobacteria are morphologically highly divergent in comparison to most other bacteria, and consequently, it has been suggested that morphological features be given more weight in the species definition (Castenholz and Norris 2005). It would be in the fitness of things if we state here species limit set for percentage of RB derived from DNA-DNA hybridization studies. Strains that show ~70% RB are considered to belong to the same species (Wayne *et al.*, 1987). As this condition cannot be applied with ease in all cases and since it would be difficult for cultivating certain strains, alternatives to this 'golden standard' have been looked for. Konstantinidis and Tiedje (2005) observed that those strains which exhibit 70% RB [or in other words those that exhibit 95% average nucleotide identity (ANI) over all shared genes] have been shown to be extremely similar in their 16S rRNA gene sequences. On the contrary, strains that have almost identical 16S rRNA gene sequences may not be closely related either on the basis of their RB (Rosselló-Móra and Amann, 2001) or ANI (Konstantinidis and Tiedje, 2005). If two strains have less than 97% sequence identity of 16S rRNA they are assigned to different species but added to this the percentage of their RB is still required in order to identify them as separate species. Since ANI represents average nucleotide identity of the total genome sequence shared between two strains, it is exceptionally a robust and sensitive method for measuring evolutionary relatedness. Strains that show more than 60% ANI exhibit greater than 97% 16S rRNA gene sequence identity. Due to a strong correlation between 95% ANI and 70% RB, Konstantinidis and Tiedje (2005) seem to favour retention of 70% RB criterion as it brings together relatively homogeneous set of strains which share at least 80% genetic homology. As ANI is a genome-derived parameter, all conserved genes between any two genomes are likely to show high degree of genetic relatedness. Moreover, there have been no reports on the organisms that show less than 98.5% identity in their 16S rRNA gene sequences and show at the same time 70% RB (Stackebrandt and Ebers, 2006) or 95% ANI. Instead of basing the phylogenetic studies on

a single gene sequence like 16S rRNA or alternatively comparing the entire genome sequences, a reasonable compromise is to select at least seven or eight core gene sequences (housekeeping genes) that can provide robust phylogeny of organisms (MLST approach; Maiden *et al.*, 1998; Gevers *et al.*, 2005). Zeigler *et al.* (2003) tested the usefulness of 32 protein-coding gene sequences, distributed widely in bacteria, in assigning bacterial strains to species. A single housekeeping gene such as *recN* (that encodes recombination/repair protein) is found to be sufficient for this purpose as strains that exhibited 96% similarity in their *recN* sequences also showed >70% similarity in their genome sequences and could be assigned with 95% confidence level to the same species. If two strains or isolates exhibit <84% similarity in the *recN* sequences, the overall similarity in the genome sequences has been found to be <70% and with the same confidence level they could be assigned to different species. The resolving power could be enhanced by the inclusion of two more genes such as *dnaX* (that encodes DNA polymerase III subunits γ , τ) and *thdF* (that encodes GTP-binding protein) in the analysis. The other housekeeping genes such as *uvrC* (excision nuclease subunit C), *uvrB* (excision nuclease subunit B), *ruvB* (Holliday Junction helicase subunit A), *dnaB* (replicative DNA helicase), *dnaJ* (chaperone with DnaK), *ftsZ* (tubulin-like cell division protein), *atpA* (ATP synthase F1, α -subunit) and *atpD* (ATP synthase F1, β -subunit) are among the other 32 genes selected by them for comparing bacterial genomes by pair-wise comparisons to arrive upon their conclusions. According to Konstantinidis and Tiedje (2007) such genes show robust phylogenetic signal and give 70–95% values of ANI. The working hypothesis for the bacterial species concept is that bacteria form coherent genome clusters with distinctive phenotypic features and the clusters seem to have been created by two major forces i.e. selection and recombination. So during selection of genes for MLST approach one should take into account LGT and recombination between the genes when one wants to identify strains within a given species. Konstantinidis *et al.* (2006) showed that selection of three such best performing genes could provide robust phylogeny and accurate prediction of ANI values. The most favourable species concepts for bacteria are biological (Mayr, 1997) and the phylogenetic concepts (Hull, 1997). These two are followed by the ecotype concept introduced by Cohan (2002) which is a variation of the phylogenetic concept. Cohan (2006) stressed the need to develop a theory-based approach to define bacterial species rather than simply recognizing the genotypic diversity based on a single molecular marker like 16S rRNA gene sequencing and demarcate bacterial species into many clusters. In doing so, the sequence clusters or OTUs should be clearly correlated to the ecotypes. Any sequence based phylogeny is likely to contain a number of subclusters and it is not clear which level of cluster corresponds to ecotypes. According to him, a conceptual framework based on the evolutionary dynamics of bacterial populations for estimating the number of ecotypes within a community and then identifying them has been proposed. Studies made on community phylogeny on three groups of organisms and their habitats revealed interesting results. The ecotypes identified in case of *Bacillus subtilis*-*B. licheniformis* occurring in Evolutionary Canyon III of Negev Desert closely corresponded to the existing species and subspecies that formed a clade in sequence-based identification. In contrast, world-wide clinical and environmental isolates of *Legionella pneumophila* could be distinguishable into 14 ecotypes that had less 16S rDNA sequence divergence. Likewise, 8 ecotypes of *Synechococcus* in A-A' Clade also exhibited less 16S rDNA sequence divergence. However, in *Synechococcus* A-A' Clade microhabitat distribution reveals one ecotype harbouring in the upper photic zone at 68°C while another ecotype is specialized to the lower photic zone suggesting that it is temperature that makes the two ecotypes distinct from one another. So in identifying a species under polyphasic taxonomy, the diagnostic ecological features would prove more meaningful. To the extent the stable ecotype model is correct, the different clusters can be equated to different

ecotypes. If some sequence clusters are not falling in the same ecotype as the most closely related strains under the species such clusters can be considered as different species.

The study of bacterial species in relation to geography is gaining interest during the past few years and is known as bacterial biogeography (Staley, 1999; Staley and Gosink, 1999; Martiny *et al.*, 2006). Evidences are in favour of the occurrence geovars of bacteria particularly in extreme environments. Staley (2006) extended the species concept based on ecological information by introducing a combined Genomic Phylogenetic Species Concept (GPSC) that is based on genomic and MLST approaches. The basic principle is that every bacterial species grows in a particular niche of its own and no two species occupy the same niche. In molecular terms, the functional proteins and enzymes produced by that particular species are unique and a true reflection of the niche. The core housekeeping genes of the species will also reflect the evolutionary pattern. In case there is a change in the niche, accordingly a genetic drift and adaptation to the new niche is a consequential event. Because GPSC takes into account sequence-based information (e.g. protein, RNA, DNA), it is more practical, rapid, readily accessible from anywhere and slowly gaining universality. To elaborate the concept of GPSC, Staley (2006) cited *Prochlorococcus* as one of the examples where a comparison between HL-adapted (MED4) and LL-adapted (MIT 9313) strains revealed interesting features. On the basis of 16S rRNA phylogeny both strains seem to have descended from a common LL-adapted ancestor. There is a great difference in the size of the genomes of the two strains. MED4 has a genome of 1.65 Mb (with a mol % G+C of 30.8) whereas MIT 9313 possesses a genome size of 2.41 Mb (with a mol% G+C of 50.7). These differences are in fact major in nature that warrants their separation into not only separate species but also into two different genera. However, their commonality is the existence of 1350 genes with additional of 364 genes in case of MED4 and 923 genes in case of MIT 9313. It is suggested that these additional genes either may have been acquired from their common ancestor (retained and duplicated) or via LGT. Although these two strains differ from each other by 0.8% of 16S rDNA sequence, the median sequence identity of the shared genes is only 78%. These two strains are considered as distinct ecotypes and GPSC concept can be readily applied to these strains.

Whitaker (2003) investigated the relationship between genetic and geographical distance in combined analysis of nine genomic loci of archaebacteria collected from globally distant geothermal regions. There appeared to be a significant distance effect that showed a distinct relationship between genetic and geographical distance among populations. Whitaker (2006) discussed allopatry as a speciation mechanism in microorganisms in which both environmental selection and geographical isolation can lead to differentiation among populations.

III. EVOLUTION OF BACTERIA AND CYANOBACTERIA

Charles Darwin (1859) presented in his classical work on “The Origin of Species” a theory of natural selection and envisaged that all organisms have evolved from a common ancestor and diverged from one another during the course of evolution. Accordingly, a universal “Tree of Life” (TOL) can be constructed representing gradual evolution of organisms. Although the concept of the existence of a common ancestor was accepted by many of his contemporaries and subsequent followers the theory of natural selection was not readily accepted. But due to the objections raised by many workers, he later modified his theory to the extent that the driving force for natural selection is spontaneous variations. One of his staunch opponents of the theory of natural selection was Thomas Morgan who strongly advocated a theory of “mutationism” that explains the evolutionary process as chiefly due to beneficial mutations. Simply because a number of mutations are of deleterious nature, this theory of Morgan was not accepted by a number of leading personalities (Fisher, 1930;

Wright, 1931; Haldane, 1932; Dobzhansky, 1937, 1951). These scientists had been ardent supporters of Darwin's theory and later this came to be known as neo-Darwinism. Zuckerkandl and Pauling (1965) were the first who put forward the idea that DNA and protein sequences can be used to draw evolutionary relationships and it is possible to construct a TOL. The studies on molecular evolution gave importance to mutations since it is due to the mutations the change in the sequence of DNA or proteins is affected. But this idea was also not acceptable to neo-Darwinians as according to them mutations have nothing to do with the phenotypic evolution. Although it was recognized that the basic underlying force for evolution is mutation and selection but subtle distinction has been made between phenotypic evolution and molecular evolution. It was noted that selection plays greater role in phenotypic evolution rather than in molecular evolution. The neutral theory of molecular evolution put forward by Kimura (1980) emphasizes 'phyletic gradualism' as the basis of evolution where the evolution of molecular characters is gradual and clock-like and that of the morphological characters can also evolve in a gradual fashion. Another aspect that lends support to this theory is mutations that occur in neutrally-evolving genes are either indifferent or negative (Kimura, 1983). Proteins encoded by neutrally-evolving genes may even show more than 70% sequence divergence but still retain the conserved function and the three-dimensional structure. It means due to a strong selection pressure the structure and function of such proteins is maintained. Thus in case of macroevolutionary characters as well there is a possibility for the retention of the same protein structure and function. However, Kimura's neutral theory suffered due to two drawbacks. The first one is that he took into account nucleotide substitutions in the whole genome instead of taking into account gene as a unit because nucleotide substitutions in the non-coding regions have no relevance in either mutation or selection. Secondly, the definition of selective neutrality took into account the probability of fixation or the time until fixation of mutation. Many molecular biologists consider a neutral or nearly neutral mutation that does not have appreciable effect on the gene function. The views expressed by King and Jukes (1969) on neutral mutations seem to be more convincing. They argued that though mutation is the primary force for evolution, the role of natural selection is to eliminate harmful mutations. According to them proteins that have rigid functional and structural constraint show lower amino acid substitutions than the proteins requiring weak functional constraints. Additional molecular data on the sequences of functionally important proteins lends support to this theory than to Kimura's computation of natural selection. Thus the concept of neutral mutations conceived by Kimura and convincingly put forward by King and Jukes is contrary to the Darwin's positive selection of adaptations but by stabilizing or purifying selection eliminates deleterious mutations allowing the fixation of neutral mutations by genetic drift. It is through the evolution of multigene families involving gene duplications and gene loss that an effect at phenotypic level would be reflected (Nei and Rooney, 2005). Taking into account these facts and other supportive molecular data Nei (1983, 1984) proposed the term neomutationism which was later called by him as neoclassical theory of evolution (Nei, 1987). Nei (2005) discussed at length the evolution of multigene families and their likely impact in shaping the evolution of new genetic systems.

The term 'phylogeny' was for the first time coined by E. Haeckel who followed Darwin's concepts and constructed phylogenetic trees for various groups of organisms. For many scientists who supported Charles Darwin the TOL is a biological fact while some others believe TOL to be a hypothesis that is yet to be proved. In view of the progress achieved in the molecular biology of prokaryotes the Darwinian concept needed a re-examination. Some of the relevant issues that require attention are as follows: (i) would it be possible to test the Darwin's theory in the context of molecular phylogenetic data obtained during recent years on prokaryotes? (ii) the phylogenetic trees built on the basis of molecular sequences would be congruent with the phylogenetic trees built on

the basis of phenotypic (morphological) features or organismal biology, (iii) can the sequence-based phylogenies provide answers and proofs of the reality of macroevolution? and (iv) how far LGT (also designated as horizontal gene transfer by some workers) affects the tree-building?

LGT is found more frequently in prokaryotes than in eukaryotes. LGT occurs in prokaryotes by means of transformation, conjugation and transduction. Genomic and phylogenetic analyses have established beyond doubt the ubiquitous occurrence of LGT among prokaryotes. Among very close relatives, homologous recombination is a great force to cause sequence divergence in many bacteria. Homologous recombination is so widespread among the strains of a designated species that even the housekeeping genes are not even spared. LGT events, on the other hand, occur across domains as for example, from Archaea to Bacteria and from Bacteria to nuclear genomes of eukaryotes. Sequencing of complete genomes and their analysis has contributed to a better understanding of LGT. On the basis of genome comparisons of bacteria and archaea, it is possible to demonstrate that major fractions of genes have been acquired through LGT events in many prokaryotes. It is significant to note that in a number of pathogenic bacteria (pathogenicity islands) and symbiotic bacteria (symbiosis islands) over 30% of the genomes are acquired through events of LGT (Hacker and Kaper, 2000; Ochman and Moran, 2001; Perna *et al.*, 2001). There are very few orthologous gene sets whose history is free of LGT (Gogarten *et al.*, 2002; Gogarten and Townsend, 2005). Even genes such as those of ribosomal proteins and RNA polymerases have not been spared (Brochier *et al.*, 2000; Makarova *et al.*, 2001; Iyer *et al.*, 2004). Based on the sequencing of *Arabidopsis*, chloroplast and cyanobacterial genomes, it was possible to identify thousands of genes of cyanobacterial endosymbiont (the chloroplast) into the host (plant) genome through LGT (Martin *et al.*, 2002). Another 'big bang' that occurred due to LGT is the evolution of mitochondria in eukaryotes. Alpha-proteobacterial ancestor of mitochondria probably invaded an archaeobacterial host triggering the genesis of a eukaryotic cell that signalled the formation of endomembrane system, cytoskeleton and the nucleus (Martin and Muller, 1998; Martin and Koonin, 2006).

There are at least three approaches to determine LGT events. The first one is to determine the atypical sequence characteristics such as codon usage bias and G+C content. Because codon usage and G+C are species-specific, it was possible to identify genes up to 18% in *E. coli* as laterally transferred genes (Lawrence and Ochman, 1998). Recent studies of Sorek *et al.* (2007) are indicative of the fact that genuine barriers for LGT in this model organism are quite low as it virtually accepted all prokaryotic genes offered to it *in vitro*. Likewise, approximately 24% of genes in *Thermotoga maritima* have come through LGT events (Garcia-Vallvé *et al.*, 2000). The second method to detect LGT is to reconstruct a phylogeny of genes. By this approach, it is possible to compare phylogenetic trees among individual genes within closely related species and recognize unusual origins of genes. The third alternative is to detect the presence/absence of genes in closely related bacteria. Though it is quite not possible to detect the number of insertion and deletion events due to gene rearrangements, it is possible to know the total number of genes due to insertions/deletions. Hao and Golding (2004) analysed 50 bacterial complete genomes from nine groups, mapped the number of gene insertions, deletions and gene duplications onto the phylogeny of the species based on 16S rRNA phylogeny. The results revealed that the number of gene insertions was much larger in the external branches of the trees and they greatly outnumbered the occurrence of deletions. At the same time, the genome sizes of these bacteria remained roughly constant suggesting that these insertions were specific to an organism and were lost before related species could evolve. Beiko and Charlebois (2007) developed a new software program known as EvolSimulator that can perform gene-, protein- and genome-scale evolutionary processes that occur in prokaryotes. It can simultaneously create lineages, gene families and sequence substitutions that can measure the levels of LGT events. Dagan *et al.* (2008)

assorted 539,723 proteins encoded among 181 prokaryotic sequenced genomes to obtain matrices of shared genes. The results revealed the existence of a network of shared genes and the genomes in the network shared at least one gene family and thus are interconnected with each other forming a complete network. They suggested that on the average $81 \pm 15\%$ of the genes in each genome were involved in LGT. Cyanobacteria possess $27 \pm 20\%$ of genes acquired in their genomes through LGT. The above account substantiates that the genomes of all organisms have evolved through LGT. If that be so, how far is it feasible to trace the evolution of all organisms from a common ancestor? Is it possible to construct a universal TOL? In addition to LGT, certain methodological problems that lead to misleading phylogenies have been highlighted by Moreira and Philippe (2000). These are (i) loss of phylogenetic signal by the accumulation of overlapping mutations, (ii) incongruity between the real evolutionary process and the assumed models of sequence evolution and (iii) differences of evolutionary rates among species or among positions within a sequence. According to Soria-Carrasco and Castresana (2008) the inconsistencies or discrepancies that are generally encountered in phylogenetic trees may also be due to phylogenetic artifacts or orthology assignment problems instead of LGT events. They traced phylogenetic inconsistencies in the three domains of life and the inconsistencies in phylogenetic trees of Proteobacteria and eukaryotes were more similar when compared with the reference tree constructed on the basis of MLST approach.

All possible explanations have been put forward for building a universal TOL. Wolf *et al.* (2002) suggested that LGT and differential gene loss are the major evolutionary phenomena in prokaryotes. On the basis of complete gene sets it would be possible to construct a TOL. Phylogenetic analysis of 220,240 proteins from 144 sequenced genomes resulted in the construction of a super tree of prokaryotes that is consistent with 16S rDNA and other molecular sequence trees. Evidences have been presented for the existence of LGT particularly among strains of *Prochlorococcus* and *Synechococcus* (Beiko *et al.*, 2005). Clemente *et al.* (2006) created a data base (at address <http://www.jaist.ac.jp/~clemente/cgi-bin/phylo.pl>) for free public use meant for phylogenetic analysis based on non-genomic data. This site consists of information on 13 organisms, 25 metabolic pathways and >1000 enzymes, compounds and reactions. A sort of pseudo-alignment of metabolic pathways is conducted that differs from a full alignment in the mapping being not necessarily one to one. The pseudo-alignment from different organisms was done in order to assess their structural similarity. The pseudo-alignment involved both graphic representation of each metabolic pathway as well as a similarity measure between individual reactions, enzymes and compounds present in the pathway. Using 61 of their 68 pathways, a phylogenetic analysis separated photosynthetic cyanobacteria from eukaryotic photosynthetic organisms. However, within cyanobacteria, it was not possible to distinguish the Chroococcales (*Synechocystis*, *Synechococcus* and *Thermosynechococcus elongatus*) from the Prochlorales (*P. marinus*, *P. marinus* sub. sp. *pastoris*), the Nostocales (*Anabaena*) and the Gloeobacterales (*Gloeobacter violaceus*). In case of other bacteria the phylogeny drawn from such analysis was found to be consistent and reasonably close to the correct taxonomy based on sequence data available with NCBI. Cottret *et al.* (2010) created a webserver known as Met Explore (freely accessible for public use at <http://metexplore.toulouse.inra.fr>) having genome-scale reconstructed metabolic networks to link metabolites identified in untargeted metabolic experiments.

Beiko *et al.* (2005) are of the view that there might infact be no universal TOL and attempts to construct such a universal TOL are futile in view of the rampant LGT events. In support of this they presented a phylogenetic analysis of 220,240 proteins from 144 sequenced genomes from which it was possible to construct a super tree that is remarkably congruent with 16S rDNA and other molecular sequence trees. But the protein trees that are strongly incongruent with a super tree node are discordant and provide evidence of LGT. This is more significantly noted in thermophiles,

pathogens and cyanobacteria. Doolittle and Baptiste (2007) questioned the fundamental belief over the existence of a universal TOL and proposed an alternative path for tree-building known as “pattern pluralism”. This theory recognizes the existence of different evolutionary models for different taxa or at different levels or for different purposes. According to them, it provides a good alternative instead of searching for an impractical universal TOL. But Koonin (2009) is of the view that the evolutionary tree introduced by Darwin need not be abandoned altogether because (i) it is possible to construct phylogenetic trees representing accurately the evolution in individual gene families, and (ii) congruent trees can be obtained for large sets of orthologous genes. There are two alternatives. One is to represent a highly consensus tree of highly conserved genes showing the LGT events. The second is to present a complex network with cross-connections representing the phases of LGT that cannot be represented as a tree. Eisen (1998) and Eisen and Fraser (2003) emphasized the need to combine the studies on whole genome sequences (genomics) and the evolutionary studies (phylogeny) together into a new composite area known as ‘phylogenomics’. According to them, LGT being a rare event has not distorted the structure of the tree. The diversity of prokaryotic genomes seems to be very enormous as revealed by the presence of good number of new genes in every sequenced genome (Tettelin *et al.*, 2005). The total number of genes present in a given species is termed as ‘pangenome’.

The root of the TOL: The classification proposed by Woese *et al.* (1990) envisages that the rooting of the TOL is between the eubacteria and archaeobacteria and that the eukaryotes were identified as specific relatives of archaeobacteria. It means the archaeobacteria constitute a more recent group than that of eubacteria. Then which are the ancestors of eubacteria and archaeobacteria that might have constituted the root from which evolution had taken place? The eubacterial group consists of gram-positive, gram-negative bacteria and cyanobacteria. So it means the prokaryotes consist of two-distinct and non-overlapping (i.e. monophyletic) groups that are not specifically related to each other than either was to the eukaryotes. Based on the presence of specific sequences of amino acids in proteins, known as ‘signature sequences’ (also termed as ‘indels’), Gupta (1998) emphasized that: (a) Archaeobacteria are monophyletic and are distinct from other prokaryotes. This conclusion is further supported by phylogenies based on gene sequences of 16s rRNA, DNA replication, transcription, translation, t-RNA splicing, histones and the Tcp-1 chaperonins. (b) Based on the signature sequences present in proteins such as HSP70, glutamine synthetase 1 (GSI) and glutamate-1-semialdehyde 2,1-aminomutase the archaeobacteria are closely related to gram-positive bacteria. (c) Signature sequences also indicate that *Deinococcus* and *Thermus* group of bacteria are intermediates in the transition from gram-positive to gram-negative bacteria. (d) Among the gram-negative bacteria, cyanobacteria constitute one of the deepest branching divisions specifically related to *Deinococcus-Thermus* group. This close relationship between these two groups is also revealed by the signature sequences unique to proteins such as DnaJ-Hsp40 and elongation factor TE-Ts sequences. These results are suggestive of a common ancestor for these two groups of prokaryotes. However, due to the existence of common signature sequences in other proteins such as Hsp60, acetolactate synthase and asparaginyl-tRNA synthetase cyanobacteria are shown to be closer to gram-negative bacteria as well. So exclusive of *Deinococcus-Thermus* group, cyanobacteria might have had a common ancestor with gram-negative bacteria. These evidences further point out to the suggestion that: (i) *Deinococcus-Thermus* group of bacteria are more ancestral than cyanobacteria; (ii) *Deinococcus-Thermus* group and cyanobacteria are not the ancestors of other gram-negative bacteria but branched off from the early ancestors. It is also probable that extensive LGT events might have taken place in between *Deinococcus-Thermus* group and cyanobacteria. The extensive sequence data further point out that the primary division within

prokaryotes is not between archaeobacteria and eubacteria (as suggested by Woese and coworkers) but between organisms that have either a monoderm cell structure (i.e. prokaryotic cells surrounded by a single membrane which includes all archaeobacteria and gram-positive bacteria) or a diderm cell structure (i.e. prokaryotic cell structure surrounded by an outer membrane which includes all the gram-negative bacteria). Gupta (1998) further suggested that the root of the prokaryotic tree or TOL lies in between (or within) archaeobacteria and gram-positive bacteria. In this connection, mention may be made of a eubacterial species *T. maritima* which had been treated as a gram-negative bacterium but later was shown to be a gram-positive one. So along with archaeobacteria the gram-positive bacteria are in fact represent ancestral lineages based on Earth's geological history and the hot and anaerobic conditions prevailed at that time were conducive for the growth of these two groups of organisms. Further it has been concluded that the ancestral eukaryotic cell is not a direct descendent of the archaeobacterial lineage but is in fact a chimera that resulted from a unique fusion event between two different groups of prokaryotes such as a thermoacidophilic archaeobacterium (monoderm) and a gram-negative eubacterium (diderm) followed by the integration of their genomes. Thus all eukaryotes (both amitochondriate and aplastidic) might have acquired the gene contributions from both these sources and retained them.

On the other hand, Cavalier-Smith (2002) presented a rooted TOL depicting the evolution of different bacterial groups from a root consisting of gram-negative bacteria. So in this respect the concepts evolved by Cavalier-Smith (2001) mostly agree with the conclusions of Woese *et al.* (1990) in recognizing the archaeobacteria as a more recent group whose ancestors have given rise to archaeobacteria on the one hand and the earliest eukaryotic organisms on the other. However, the difference lies in recognizing the root of the TOL. Accordingly, the roots identified by the three groups of workers are (i) ancestors between eubacteria and archaeobacteria (Woese *et al.*, 1990), (ii) ancestors between archaeobacteria and gram-positive bacteria (Gupta, 1998) and (iii) ancestors between archaeobacteria and gram-negative bacteria (Cavalier-Smith, 2001).

According to Cavalier-Smith (2002) life on planet Earth most likely has evolved ~3850 million years (My) ago. Negibacteria (in Latin 'Negi' means negative, i.e. gram-negative bacteria) with a double peptidoglycan layer of cell wall, porins, acyl ester phospholipids, photosynthesis and chlorosomes appeared at the base ~3400 My ago that formed the root for the TOL. Evolution diverged into cyanobacteria and Eobacteria (in Latin 'Eo' means dawn or early). At about ~2500 My ago cyanobacterial branch gave rise to Eubacterial group comprising Posibacteria ('Posi' for gram-positive bacteria with endospores-Endobacteria) and Actinobacteria (comprising Arthrobacteria, Streptomyces and Arbobacteria). Thermophilic ancestors of Eubacteria called as Neomura gave rise (~850 My ago) to Archaeobacteria and Eukaryota (Fig. 22). The line from Eobacteria diverged separately into Spirochaetes (~2500 My ago after cyanobacteria have evolved), Planctobacteria and Proteobacteria. It is the Proteobacteria that probably formed the ancestors for mitochondrial development during the time of appearance of primitive eukaryotes which had mesophily and phagotrophy as their properties. In this bacterial megaclassification he recognized one Kingdom (as per Bacteriological Code) instead of a Domain and Enterobacteriales as the Type order. He considered the term as 'Eubacteria' as a useful grade name but not treated in his classification as a taxon. The Bacteria are divided into two new subkingdoms. Subkingdom I consists of Negibacteria (with a cell envelope of two distinct genetic membranes) and Unibacteria (consisting of new phyla Archaeobacteria and Posibacteria). A number of morphological, palaeontological and molecular data have been integrated to present a unified picture of bacterial cell evolution despite occasional LGT events. Archaeobacteria and eukaryotes comprise the clade neomura. There are some characters unique (8 of them) to Archaeobacteria of which mention may be made of the absence of Hsp90 chaperone, the splitting of RNA polymerase into two proteins and

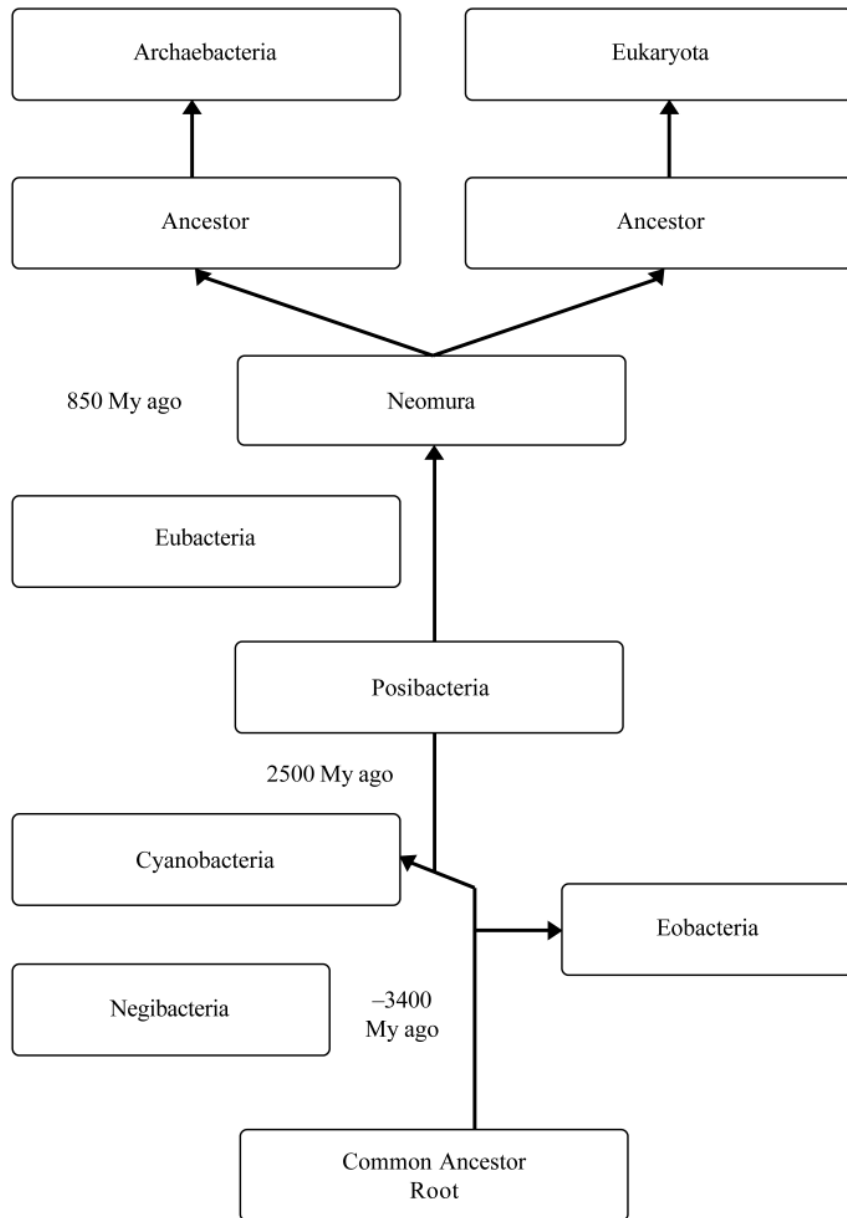


Figure 22: Phylogenetic tree with a common ancestor for the evolution of living organisms. Based on Cavalier-Smith (2002).

the splitting of glutamine synthetase into three separate proteins. Archaeobacteria share 19 characters with eukaryotes that are not found in eubacteria.

Fossil evidences suggest that life on the planet Earth might have had its origins in the Precambrian eon and during the subsequent span of 542 My the evolution of the present day flora and fauna could be traced through the Palaeozoic, Mesozoic and Coenozoic ages, collectively known as

Phanerozoic age. According to the norms set by the International Commission on Stratigraphy, seven chronostratigraphic units have been recognized in the Precambrian period. These are Palaeoproterozoic (2000–1650 My), Lower Mesoproterozoic (1650–1200 My), Upper Mesoproterozoic (1200–1030 My), Lower Neoproterozoic (1030–850 My), Upper Neoproterozoic (850–630 My), Lower Edicaran (630–550 My) and Upper Edicaran (550–542 My) units (Sergeev, 2009). The evolution and distribution of life in the Precambrian era has been reviewed (Sharma and Shukla, 2009). Fossil microflora, dating to Late Precambrian, from Bitter Spring Formation of Central Australia has been reported (Schopf, 1968). Schopf and Walter (1983) reported simple trichomes of Oscillatorian cyanobacteria from ~2800 My Fortescue Group, Western Australia. Further evidences on the existence of microfossils of the early Archaean Apex Chert (Schopf, 1993) and Laser-Raman imagery of the Earth's earliest fossils (Schopf *et al.*, 2002) have been presented. Some of the fossils of cyanobacteria have been traced to ~2,100 My from Franceville Group of Gabon formations. These are represented mostly by coccoid, star-like, filament, tubular forms and nostocacean akinetes i.e. *Archaeoellipsoides* (Amard and Bertrand-Sarfati, 1997). *Archaeoellipsoides* is a well preserved representative occurring abundantly in the ~1500 My Cherts from Billyakh group of Siberia (Golubic *et al.*, 1995). This genus has also been found in the silicified carbamates of the ~1650 My Amelia Dolomite of northern Australia (Page *et al.*, 2000) as well as 1631±5-My Cherts from the Kheinjua Formation in India (Srivastava, 2005).

Rudi *et al.* (1998) studied the evolutionary rates in a number of strains of cyanobacteria (16 strains of *Microcystis*, 6 strains of *Tychonema*, 10 strains of *Planktothrix* and 12 strains of *Nostoc*) by comparing sequence divergence in the neutrally-evolving genes such as *rbcL* and *rbcX* and compared them with 16S rRNA phylogeny. While there was low sequence divergence within *Microcystis*, *Tychonema* and *Planktothrix* for *rbcLX* and 16S rDNA, strains of *Nostoc* revealed three genetically clustered lineages for these genes. The 16S rDNA and *rbcLX* phylogenies were not congruent with those in the clustered groups. The evolutionary model presented by them explains as to how the modern species has evolved by sequence homogenization involving extensive exchange of genetic material for neutrally-evolving genes. Further, they emphasized that the macroevolutionary characters or morphological characters have been stable for long periods if a comparison is made between the fossils and present day representatives of cyanobacteria. This is likely to be achieved by exchange of genetic material between phyletically closely related strains of cyanobacteria for neutrally-evolving genes. This is supported by the existence of greater sequence homogeneity for the closely related cyanobacteria and the exchange of genetic material probably stabilizes the function and structure of proteins. According to Rudi *et al.* (1998) their model of gene transfer explains the morphological similarities between the fossil and the recent species.

Due to selection pressures operative in the populations of pure cultures, the genotype that dominates is other than the dominant genotype in the natural population at the time of collection. So a culture thus no longer represents the dominant genotype supposed to represent the type specimen. Due to this departure, how far is it justified to extrapolate the results from the laboratory to the field samples? Additionally, if phylogenetic analysis of field samples is done directly (circumventing the process of culture techniques) by metagenomics, a situation arises where we have a sequence identified without any proper identification of the organism based on classical morphological or a polyphasic approach (Ward *et al.*, 1994; Amann *et al.*, 1995). It means at the time the type species is proposed, it has to be genetically characterized. Now the situation is that whatever type species for the representative taxa of cyanobacteria we have now, they lack genetic characterization. Palinska *et al.* (2006) presented evidences to show that historic identifications made on the basis of classical taxonomy could be confirmed by subjecting herbarium specimens to microscopic (light and electron

microscopy) and molecular methods of analysis (16S rRNA gene amplification and its sequence comparisons). They obtained materials deposited at the Herbariums of University of Vienna (HUW) and Swedish Museum of Natural History, Stockholm (SH) by workers other than those who discovered them in the corresponding years mentioned after the name of the species. They included representatives of unicellular [*Microcystis* (*Polycystis*) *aeruginosa* Kützinger 1885 and *Chroococcus turgidus* Kützinger 1850 of Section II], filamentous, non-heterocystous [*Microcoleus chthonoplastes* (Mertens) Zanardini ex Gomont 1895 and *Trichodesmium erythraeum* Ehrenberg ex Bornet et Flahault 1884 of Section III] and filamentous, heterocystous forms [*Nostoc muscorum* Agardh ex Bornet et Flahault 1886 and *Nodularia spumigena* Bornet et Flahault 1906 of Section IV of Rippka *et al.* (1979)]. *T. erythraeum* was obtained from SH and the rest were from HUW. They are of the opinion that though these specimens were not characterized genetically at the time collection, the preserved type materials in all these cases had the advantage of permanently retaining the characteristics of the specimens noted at the time of collection. In this connection, the suggestions of Castenholz and Norris (2005) are worth recalling who emphasized that the morphological features be given more weightage in the species definition of cyanobacteria.

Zhaxybayeva *et al.* (2006) developed a tool that helps in comparing phylogenetic trees constructed for each of the orthologous genes detected in four taxa at a time. This method is known as “embedded quartet decomposition analysis” or “quartet decomposition”. They included 11 completely sequenced genomes (*Anabaena* sp. strain PCC 7120, *T. erythraeum* IMS101, *Synechocystis* sp. strain PCC 6803, *P. marinus* CCMP1375, *P. marinus* MED4, *P. marinus* MIT9313, marine *Synechococcus* WH 8102, *T. elongatus* BP-1, *Gloeobacter violaceus* PCC 7421; *Nostoc punctiforme* ATCC 29133 and *Crocospheera watsonii* WH8501) in their study that represent freshwater, marine and hot spring cyanobacteria. A comparison of 1128 protein-coding gene families from these genomes revealed the existence of 879 homologues in selected prokaryotic genomes and the remaining 249 data sets have been found to be “cyanobacteria-specific”. According to them, these “cyanobacteria-specific” homologue gene sequences are not suitable for interphylum transfers but 700 of the 879 gene data sets are highly resolved and 80% of these are distributed in cyanobacteria. Of the 700 genes, 540 support cyanobacteria as a coherent group (accounting to $\approx 77\%$) while the remaining 160 gene sequences ($\approx 23\%$) either have sequences interspersed among cyanobacteria or some cyanobacterial gene sequences being found elsewhere. This suggests for a possibility of transfer events to or from cyanobacteria. Zhaxybayeva *et al.* (2009) extended the embedded quartet scatter plots to understand gene flow in the intertwined evolutionary histories of 18 *P. marinus* and *Synechococcus* genomes. The conclusions are that: (i) the HL-adapted *P. marinus* strains constitute a monophyletic clade; (ii) the LL-adapted *P. marinus* strains form a paraphyletic clade; (iii) frequent transfer of at least 16 gene families took place between HL- and LL-adapted strains and (iv) high way of gene sharing occurred between *Synechococcus* spp. and LL-adapted *P. marinus* strains to the extent of erosion of genus boundaries, supporting the observations of Beiko *et al.* (2005). According to them, however, these events have not disturbed the *Prochlorococcus*-specific ecological adaptations. Other estimates of LGT point out that cyanobacteria might have acquired between 9.5% and 16.6% genes through LGT (Ochman *et al.*, 2000; Nakamura *et al.*, 2004). These estimates are on a lower side when compared to $27 \pm 20\%$ of genes acquired through LGT by cyanobacteria as mentioned earlier (Dagan *et al.*, 2008).

IV. THE OTHER SIDE OF THE COIN

The impact of 16S rDNA sequencing in prokaryotic world is so enormous for the simple reason it has generated a great wealth of information on microbial diversity, community structure and phylogenetic relationships from diverse environments and geographic regions. Moreover, the impact seems to have left an impression in the minds of many investigators that it is the key for unraveling the taxonomic disputes of cultivable and uncultivable organisms. A lot of confusion seems to have been generated on the existence of a number of “computer bacteroids” based on the existence of only sequences from metagenomic analyses. There are no nomenclatural guidelines existing in bacterial taxonomy for recognizing only sequences as equivalent to organisms. Murray and Schleifer (1994) stated that international nomenclatural code “is not able to provide sensible regulation of nomenclature for new taxa defined by very limited data”. It is pertinent to point out that the original bacteriological code written in 1957 and the considerations of the Judicial Commission (both in 1976 and 1990) have not foreseen a situation for consideration of bacterial taxa based on only molecular sequences. There are a number of pitfalls in this area. Some of the fears expressed are that (i) the molecular sequences are based on samples of relatively small size, (ii) a sampling error can not be ruled out, (iii) likewise, errors in sequencing can not be ruled out, (iv) specially with reference to 16S rRNA gene sequencing studies, contaminating 16S rDNA in the sample can not be overlooked, (v) a number of workers considered only a single strain of a taxon such as a genus yet the picture presented was for the entire taxon and even the validity of the adjacent taxa was questioned. Gest (1999) presented “a primer for the new millennium” to lift bacterial classification and taxonomy from its existing “chaotic status”. He quoted extensively the opinions of many scientists on the role of molecular markers and the validity of phylogeny based taxonomy. According to him there is a complete disregard to bacterial nutrition, physiology and biochemistry based on which many basic principles in cell biology and biochemistry have been enunciated.

The current situation in cyanobacterial taxonomy is more disconcerting for both the traditional as well as the molecular taxonomist. The first major requirement is a classification that resolves the guidelines of both ICBN and International Code of Nomenclature of Prokaryotes (ICNP). Moreover, the guidelines for nomenclature and a polyphasic approach to the taxonomy of cyanobacteria have not been clearly defined. Pinevich (2008) summarized and highlighted the paradoxes of biodiversity, phylogeny and taxonomy of cyanobacteria. Though it is needless to repeat here the inconsistencies in cyanobacterial taxonomy, one taxonomic riddle could not be resolved despite the progress that has been achieved by the application of molecular markers. This relates to the identification of *Anabaena* sp. strain PCC 7120. More than half a dozen research papers have been published in support of it being designated as *Anabaena* sp. strain PCC 7120 while as many number of research papers have been published in support of it being redesignated as *Nostoc* sp. strain PCC 7120. The present trend is that many workers started representing it as *Anabaena/Nostoc* sp. strain PCC 7120. What is the signal that is sent to the traditional taxonomist who finds it difficult to enter into the woods of phylogenetic trees? Oren (2011) highlighted the inadequacies in the resolution of guidelines between ICBN and ICNP and suggested that ‘the guidelines for the characterization of prokaryotic strains for taxonomic purposes advocated by Tindall *et al.* (2010) be adopted for nomenclatural guidelines of cyanobacteria’. Unless a major international effort is undertaken, the cyanobacterial taxonomy continues to lie in the same state for another century. It is because it took more than 60 years to identify and classify very few cyanobacterial strains on a polyphasic approach (Oren, 2011).

LITERATURE CITED

- Abe, T., Kanaya, S., Kinouchi, M., Ichiba, Y., Kozuki, T., and Ikemura, T. (2003) Informatics for unveiling hidden genome signatures. *Genome Res* **13**: 693–702.
- Abed, R. M. M., and Garcia-Pichel, F. (2001) Long-term compositional changes after transplant in a microbial mat cyanobacterial community revealed using a polyphasic approach. *Environ Microbiol* **3**: 53–62.
- Abed, R. M. M., Garcia-Pichel, F., and Hernández-Mariné, M. (2002a) Polyphasic characterization of benthic, moderately halophilic, moderately thermophilic cyanobacteria with very thin trichomes and the proposal of *Halomicronema excentricum* gen. nov., sp. nov. *Arch Microbiol* **177**: 361–370.
- Abed, R. M. M., Safi, N. M. D., Köster, J., De Beer, D., El-Nahal, Y., Rullkötter, J., and Garcia-Pichel, F. (2002b) Microbial diversity of a heavily polluted microbial mat and its community changes following degradation of petroleum compounds. *Appl Environ Microbiol* **68**: 1674–1683.
- Acinas, S. G., Haverkamp, T. H. A., Huisman, J., and Stal, L. J. (2009) Phenotypic and genotypic diversification of *Pseudoanabaena* spp. (Cyanobacteria). *ISME J* **3**: 31–46.
- Al-Thukair, A. A., Abed, R. M. M., and Mohamed, L. (2007) Microbial community of cyanobacteria mats in the intertidal zone of oil-polluted coast of Saudi Arabia. *Mar Pollut Bull* **54**: 173–179.
- Amann, R. I., Binder, B. J., Olson, R. J., Chisholm, S. W., Devereux, R., and Stahl, D. A. (1990) Combination of 16S rRNA-targeted oligonucleotide probes with flow cytometry for analyzing mixed microbial populations. *Appl Environ Microbiol* **56**: 1919–1925.
- Amann, R. I., Ludwig, W., and Schleifer, K.-H. (1995) Phylogenetic identification and *in situ* detection and identification of individual microbial cells with out cultivation. *Microbiol Rev* **59**: 143–169.
- Amard, B., and Bertrand-Sarfati, J. (1997) Microfossils in 2000 Ma old cherty stromatolites of the Franceville Group, Gabon. *Precambrian Res* **81**: 197–221.
- Amikam, D., Glaser, G., and Razin, S. (1984) Mycoplasmas (*Mollicutes*) have a low number of rRNA genes. *J Bacteriol* **158**: 376–378.
- Anagnostidis, K., and Komárek, J. (1985) Modern approach to the classification system of the Cyanophytes 1: Introduction. *Arch Hydrobiol* **71**: 291–302.
- Anagnostidis, K., and Komárek, J. (1988) Modern approach to the classification system of cyanophytes. 3. Oscillatoriales. *Arch Hydrobiol* suppl **80**: 327–472.
- Antón, A. I., Martínez-murcia, A. J., and Rodríguezvalera, F. (1998) Sequence diversity in the 16S-23S intergenic spacer region (ISR) of the rRNA operons in representatives of the *Escherichia coli* ECOR collection. *J Mol Evol* **47**: 62–72.
- Barker, G. L., Hayes, P. K., O'Mahony, S. L., Vacharapiyasophon, P. and Walsby, A. E. (1999) A molecular and phenotypic analysis of *Nodularia* (cyanobacteria) from the Baltic Sea. *J Phycol* **35**: 931–937.
- Barker, G. L., Handley, B. A., Vacharapiyasophon, P., Stevens, J. R., and Hayes, P. K. (2000) Allele-specific PCR shows that genetic exchange occurs among genetically diverse *Nodularia* (cyanobacteria) filaments in the Baltic Sea. *Microbiology* **146**: 2865–2875.
- Beiko, R. G., and Charlebois, R. L. (2007) A simulation test bed for hypotheses of genome evolution. *Bioinformatics* **23**: 825–831.
- Beiko, R. G., Harlow, T. J., and Ragan, M. A. (2005) Highways of gene sharing in prokaryotes. *Proc Natl Acad Sci USA* **102**: 14332–14337.
- Beltran, E. C., and Neilan, B. A. (2000). Geographical segregation of the neurotoxin-producing cyanobacterium *Anabaena circinalis*. *Appl Environ Microbiol* **66**: 4468–4474.
- Ben-Porath, J., Carpenter, E. J., and Zehr, J. P. (1993) Genotypic relationships on *Trichodesmium* (Cyanophyceae) based on *nifH* sequence comparisons. *J Phycol* **29**: 806–810.
- Bensaadi-Merchermek, N., Salvado, J.-C., Cagnon, C., Karama, S., and Mouchés, C. (1995). Characterization of the unlinked 16S rDNA and 23S-5S rRNA operon of *Wolbachia pipientis*, a prokaryotic parasite of insect gonads. *Gene* **165**: 81–86.
- Benson, D. A., Karsch-Mizrachi, I., Lipman, D. J., Ostell, J., Rapp, B. A., and Wheeler, D. L. (2002) GenBank. *Nucleic Acids Res* **30**: 17–20.
- Bent, B. J., Pierson, J. D., and Forney, L. J. (2007) Measuring richness based on microbial community fingerprints: the Emperor has no clothes. *Appl Environ Microbiol* **73**: 2399–2401.
- Bercovier, H., Kafri, O., and Sela, S. (1986) Mycobacteria possess a surprisingly small number of ribosomal RNA genes in relation to the size of their genome. *Biochem Biophys Res Commun* **136**: 1136–1141.
- Berrendero, E., Perona, E., and Mateo, P. (2008) Genetic and morphological characterization of *Rivularia* and *Calothrix* (Nostocales, Cyanobacteria) from running water. *Int J Syst Evol Microbiol* **58**: 447–460.
- Binder, B. J., and Liu, Y. C. (1998) Growth rate regulation of rRNA content of a marine *Synechococcus* (cyanobacterium) strain. *Appl Environ Microbiol* **64**: 3346–3351.

- Bittencourt-Oliveira, M. do. C., Moura, A. do. N., Oliveira, M. C. de., and Massola Jr., N. S. (2009) *Geitlerinema* species (Oscillatoriales, Cyanobacteria) revealed cellular morphology, ultrastructure and DNA sequencing. *J Phycol* **45**: 716–725.
- Blackwood, C. B., and Buyer, J. S. (2007) Evaluating the physical capture method of terminal restriction fragment length polymorphism for comparison of soil microbial communities. *Soil Biol Biochem* **39**: 590–599.
- Blackwood, C. B., Marsh, T., Kim, S-H., and Paul, E. A. (2003) Terminal restriction fragment length polymorphism data analysis for quantitative comparison of microbial communities. *Appl Environ Microbiol* **69**: 926–932.
- Blackwood, C. B., Hudleston, D., Zak, D. R., and Buyer, J. S. (2007) Interpreting ecological diversity indices applied to terminal restriction length polymorphism data: Insights simulated microbial communities. *Appl Environ Microbiol* **73**: 5276–5283.
- Bolch, C. J. S., Orr, P., Jones, G. J., and Blackburn, S. J. (1999) Genetic, morphological and toxicological variation among globally distributed strains of *Nodularia* (Cyanobacteria). *J Phycol* **35**: 339–355.
- Boone, D. R., and Castenholz, R. W. (Eds.) (2001). *Bergey's Manual of Systematic Bacteriology*, 2nd edn., Vol. 1. Springer-Verlag, New York, NY, USA.
- Bornet, E., and Flahault, C. (1888) Revision des Nostocacées. *Ann Sci Nat Bot* **3**: 323–381, **4**: 343–373, **5**: 51–129, **7**: 177–262.
- Boucher, Y., Douady, C. J., Sharma, A. K., Kamekura, M., and Doolittle, W. F. (2004) Intragenomic heterogeneity and intergenomic recombination among haloarchaeal rRNA genes. *J Bacteriol* **186**: 3980–3990.
- Bouchet, V., Huot, H., and Goldstein, R. (2008) Molecular genetic basis of ribotyping. *Clinical Microbiol Rev* **21**: 262–273.
- Bourelly, P. (1970) *Les algues d'eau douce III*. N Boubée et cie, Paris, pp.512.
- Boutte, C., Grubisic, S., Balthasart, P., and Wilmotte, A. (2006) Testing of primers for the study of cyanobacterial molecular diversity by DGGE. *J Microbiol Methods* **65**: 542–550.
- Boyer, S. L., Flechtner, V. R., and Johansen, J. R. (2001) Is the 16S–23S rRNA Internal transcribed spacer region a good tool for use in molecular systematics and population genetics? A case study in cyanobacteria. *Mol Biol Evol* **18**: 1057–1069.
- Brochier, C., Philippe, H. and Moreira, D. (2000) The evolutionary history of ribosomal protein Rps14: horizontal gene transfer at the heart of the ribosome. *Trends Genet* **16**: 529–533.
- Brown, M. V., Schwalbach, M. S., Hewson, I., and Fuhrman, J. A. (2005) Coupling 16S-ITS rDNA clone libraries and automated ribosomal intergenic spacer analysis to show marine microbial diversity: development and application to a time series. *Environ Microbiol* **7**: 1466–1479.
- Buchanan, R. E., and Gibbons, N. E. (Eds.) (1974) *Bergey's Manual of Determinative Bacteriology*. Williams and Wilkins Co., Baltimore, MD, USA.
- Callejas, C., Gill, P. R., Catalán, A. I., Aziz, G., Castro-Sowinski, S., and Batista, S. (2010) Phylotype diversity in a benthic cyanobacterial mat community on King George Island, maritime Antarctica. *World J Microbiol Biotechnol* doi: 10.1007/s11274-010-0578-1
- Carpenter, E. J. (1983) Nitrogen fixation by marine *Oscillatoria* (*Trichodesmium*) in the world's oceans. In: Carpenter, E. J., and Capone, D.G. (Eds.) *Nitrogen in the Marine Environment*. Academic Press, New York, NY, USA. pp. 65–103.
- Castenholz, R. W. (1992) Species usage, concept, and evolution in the cyanobacteria (blue–green algae). *J Phycol* **28**: 737–745.
- Castenholz, R. W. (2001) Phylum BX. Cyanobacteria. In: Boone, D. R., and Castenholz, R. W. (Eds.) *Bergey's Manual of Systematic Bacteriology*, 2nd edn., Vol. 1.: Springer-Verlag, New York, NY, USA. pp. 473–487.
- Castenholz, R. W., and Norris, T. B. (2005) Revisionary concepts of species in the cyanobacteria and their applications. *Arch Hydrobiol Algol Stud* **117**: 53–69.
- Castenholz, R. W., and Waterbury, J. B. (1989) Group I. Cyanobacteria. In: Krieg, N. R., and Holt, J. G. (Eds.) *Bergey's Manual of Systematic Bacteriology*, vol. 3: Williams & Wilkins, Baltimore, MD, USA. pp. 1710–1728.
- Castiglioni, B., Rizzi, E., Frosini, A., Sivonen, K., Rajaniemi, P., Rantala, A., Mugnai, M.A., Ventura, S., Wilmotte, A., Boutte, C., Grubisic, S., Balthasart, P., Consolandi, O., Bordoni, R., Mezzelani, A., Battaglia, C., and De Bellis, G. (2004) Development of a universal microarray based on the ligation detection reaction and 16SrRNA gene polymorphism to target diversity of cyanobacteria. *Appl Environ Microbiol* **70**: 7161–7172.
- Cavalier-Smith, T. (2001) Obcells as proto-organisms: membrane heredity, lithophosphorylation, and the origins of the genetic code, the first cells, and photosynthesis. *J Mol Evol* **53**: 555–595.
- Cavalier-Smith, T. (2002) The neomuran origin of archaeobacteria, the negibacterial root of the universal tree and bacterial megaclassification. *Int J Syst and Evol Microbiol* **52**: 7–76.
- Chen, F., Wang, K., Kan, J., Suzuki, M. T., and Wommack, K. E. (2006) Diverse and unique picocyanobacteria in Chesapeake Bay, revealed by 16S–23S rRNA internal transcribed spacer sequences. *Appl Environ Microbiol* **72**: 2239–2243.
- Chen, X., and Widger, W. R. (1993) Physical genome map of the unicellular cyanobacterium *Synechococcus* sp. strain PCC 7002. *J Bacteriol* **175**: 5106–5116.
- Chenna, R., Sugawara, H., Koike, T., Lopez, R., Gibson, T. J., Higgins, D. G., and Thompson, J. D. (2003) Multiple sequence alignment with the Clustal series of programs. *Nucleic Acids Res* **31**: 3497–3500.

- Chisholm, S. W. (1992) Phytoplankton size. In: Falkowski, P. G. and Woodhead, A. D. (Eds.) *Primary Productivity and Biogeochemical Cycles in the Sea*. Plenum Press, New York, NY, USA. pp. 213–237.
- Chisholm, S. W., Frankel, S. L., Goericke, R., Olson, R. J., Palenik, B., Waterbury, J. B., West-Johnsrud, L., and Zettler, E. R. (1992) *Prochlorococcus marinus* nov. gen. nov. sp.: an oxyphototrophic marine prokaryote containing divinyl chlorophyll *a* and *b*. *Arch Microbiol* **157**: 297–300.
- Chisholm, S. W., Olson, R. J., Zettler, E. R., Goericke, R., Waterbury, J., and Welschmeyer, N. (1988) A novel free-living prochlorophyte abundant in the oceanic euphotic zone. *Nature* (London) **334**: 340–343.
- Clemente, J. C., Satou, K., and Valiente, G. (2006) Phylogenetic reconstruction from non-genomic data. *Bioinformatics* **23**: e110–e115. doi: 10/bioinformatics/bt1307
- Cohan, F. M. (2002) What are bacterial species? *Annu Rev Microbiol* **56**: 457–487. doi: 10.1146/annurev.micro.56.012302.160634
- Cohan, F. M. (2006) Towards a conceptual and operational union of bacterial systematic, ecology and evolution. *Phil Trans R Soc B* **361**: 1985–1996.
- Cohn, F. (1872) Grundzüge einer neuen natürlichen Anordnung der Kryptogamischen Pflanzen. *Jarhb Schles Ges Vaterl KuH* **49**: 83–89.
- Cohn, F. (1875) Untersuchungen über Bakterien. II. *Beitr Biol Pflanz* **1**: 141–207.
- Cottret, L., Wildridge, D., Vinson, F., Barrett, M. P., Charles, H., Sagot, M. F., and Jourdan, F. (2010) Met Explore: a webserver to link metabolic experiments and genome-scale metabolic networks. *Nucleic Acids Res* **38**: W132–W137. doi: 10.1093/nar/gicq312
- Crosbie, N. D., Pöckl, M., and Weisse, T. (2003) Dispersal and phylogenetic diversity of nonmarine picocyanobacteria, inferred from 16S rRNA gene and *cpc*-intergenic spacer sequence analysis. *Appl Environ Microbiol* **69**: 5716–5721.
- D’Auria, G., Pushker, R., and Rodríguez-Valera, F. (2006) IWoCS: analyzing ribosomal intergenic transcribed spacers configuration and taxonomic relationships. *Bioinformatics* **22**: 527–531.
- Dagan, T., Artzy-Randrup, Y., and Martin, W. (2008) Modular networks and cumulative impact of lateral transfer in prokaryote genome evolution. *Proc Natl Acad Sci USA* **105**: 10039–10044.
- Danovaro, R., Luna, G. M., Dell’Anno, A., and Pietrangeli, B. (2006) Comparison of two fingerprinting techniques, terminal restriction fragment length polymorphism and automated ribosomal intergenic spacer analysis, for determination of bacterial diversity in aquatic environments. *Appl Environ Microbiol* **72**: 5982–5989.
- Darwin, C. (1859) *On the Origin of Species*. Murray, London.
- Darwin, C. (1872) *The Origin of Species*. 6th edn. Murray, London.
- Desikachary, T. V. (1959) *Cyanophyta*. Indian Council Agricultural Research, New Delhi.
- De Vos, P., and Trüper, H. G. (2000) Judicial Commission of the International Committee on Systematic Bacteriology. IXth International (IUMS) Congress of Bacteriology and Applied Microbiology. Minutes of the meetings, 14, 15 and 18 August 1999, Sydney, Australia. *Int J Syst Evol Microbiol* **50**: 2239–2244.
- Dobzhansky, T. (1937) *Genetics and the Origin of Species*. Columbia University Press, New York, NY, USA.
- Dobzhansky, T. (1951) *Genetics and the Origin of Species*. 2nd edn. Columbia University Press, New York, NY, USA.
- Doolittle, R. F., Feng, D. F., Tsang, S., Cho, G., and Little, E. (1996) Determining divergence times of the major kingdoms of living organisms with a protein clock. *Science* **271**: 470–477.
- Doolittle, W. F., and Bapteste, E. (2007) Pattern pluralism and the tree of life hypothesis. *Proc Natl Acad Sci USA* **104**: 2043–2049.
- Drouet, F. (1981) Revision of the Stigonemataceae with a summary of the classification of the blue-green algae. *Nova Hedwigia* **66**: 1–221.
- Drouet, F., and Daily, W. A. (1956) Revision of the coccoid Myxophyceae. *Butler University Botanical Studies* **12**: 1–218.
- Dunbar, J., Ticknor, L. O., and Kuske, C. R. (2000) Assessment of microbial diversity in four southwestern United States soils by 16S rRNA gene terminal restriction fragment analysis. *Appl Environ Microbiol* **66**: 2943–2950.
- Dunbar, J., Ticknor, L. O., and Kuske, C. R. (2001) Phylogenetic specificity and reproducibility and new method for analysis of terminal restriction fragment profiles of 16S rRNA genes from bacterial communities. *Appl Environ Microbiol* **67**: 190–197.
- Egholm, M., Buchardt, O., Christensen, L., Behrens, C., Freler, S. M., Driver, D. A., Berg, R. H., Kim, S. K., Norden, B., and Nielsen, P. E. (1993) PNA hybridizes to complementary oligonucleotides obeying the Watson-Crick hydrogen bonding rules. *Nature* (London) **365**: 266–268.
- Eisen, J. A. (1998) Phylogenomics: Improving functional predictions for uncharacterized genes by evolutionary analysis. *Genome Res* **8**: 163–167.
- Eisen, J. A., and Fraser, C. M. (2003) Phylogenomics: Intersection of evolution and genomics. *Science* **300**: 1706–1707.
- El Fantroussi, S., Urakawa, H., Bernhard, A. E., Kelly, J. J., Noble, P. A., Smidt, H., Yershov, G. M. and Stahl, D. A. (2003) Direct profiling of environmental microbial populations by thermal dissociation analysis of native rRNAs hybridized to oligonucleotide microarrays. *Appl Environ Microbiol* **69**: 2377–2382.

- El Herry, S., Nasri, H., and Bouaïcha, N. (2008) Morphological and phylogenetic analysis of colonies of *Microcystis* morphospecies isolated from the Lebna Dam, Tunisia. *Afr J Microbiol Res* **2**: 340–348.
- Engelbreton, J. J., and Moyer, C. L. (2003) Fidelity of select restriction endonucleases in determining microbial diversity by terminal-restriction fragment length polymorphism. *Appl Environ Microbiol* **69**: 4823–4829.
- Ernst, A., Marschall, P., and Postius, C. (1995) Genetic diversity among *Synechococcus* spp. (cyanobacteria) isolated from the pelagial of Lake Constance. *FEMS Microbiol Ecol* **17**: 197–204.
- Ernst, A., Becker, S., Wollenzien, U. I. A., and Postius, C. (2003) Ecosystem dependent adaptive radiations of picocyanobacteria inferred from 16S rRNA and ITS-1 sequence analysis. *Microbiology* **149**: 217–228.
- Fantroussi, S. E., Urakawa, H., Bernhard, A. E., Kelly, J. J., Noble, P. A., Smidt, H., Yershov, G. M., and Stahl, D. A. (2003) Direct profiling of environmental microbial populations by thermal dissociation analysis of native rRNAs hybridized to oligonucleotide microarrays. *Appl Environ Microbiol* **69**: 2377–2382.
- Felsenstein, J. (1989) PHYLIP-Phylogeny Inference Package (version 3.2). *Cladistics* **5**: 164–166.
- Fergusson, K. M., and Saint, C. P. (2000) Molecular phylogeny of *Anabaena circinalis* and its identification in environmental samples by PCR. *Appl Environ Microbiol* **66**: 4145–4148.
- Ferris, M. J., and Ward, D. M. (1997) Seasonal distributions of dominant 16S rRNA defined populations in a hot spring microbial mat examined by denaturing gradient gel electrophoresis. *Appl Environ Microbiol* **63**: 1375–1381.
- Ferris, M. J., Kühl, M., Wieland, A., and Ward, D. M. (2003) Cyanobacterial ecotypes in different optical microenvironments of a 68 °C hot spring mat community revealed by 16S–23S rRNA internal transcribed spacer region variation. *Appl Environ Microbiol* **69**: 2893–2898.
- Fisher, R. A. (1930) *Genetical Theory of Natural Selection*. Oxford University Press, Oxford, England, UK.
- Floyd, M. M., Tang, J., Kane, M., and Emerson, D. (2005) Captured diversity in a culture collection. Case study of the geographic and habitat distributions of environmental isolates held at the American Type Culture Collection. *Appl Environ Microbiol* **71**: 2813–2823.
- Foerstner, K. U., von Mering, C., and Bork, P. (2006) Comparative analysis of environmental sequences: potential and challenges. *Phil Trans R Soc B* **361**: 519–523.
- Fraser, C., Alm, E. J., Polz, M. F., Spratt, B. G., and Hanage, W. P. (2008) The bacterial species challenge: making sense of genetic and ecological diversity. *Science* **323**: 741–746.
- Fritsch, F. E. (1945) *The Structure and Reproduction of Algae, vol II*. Cambridge University Press, Cambridge, England, UK.
- Fox, G. E., Peckman, K. J., and Woese, C. R. (1977) Comparative cataloging of 16S ribosomal ribonucleic acid: molecular approach to prokaryotic systematics. *Int J Syst Bacteriol* **27**: 44–57.
- Fox, G. E., Wisotzkey, J. D., and Jurtshuk Jr., P. (1992) How close is close: 16S rRNA sequence identity may not be sufficient to guarantee species identity. *Int J Syst Bacteriol* **42**: 166–170.
- Fukunaga, M., and Mifuchi, I. (1989). Unique organization of *Leptospira interrogans* rRNA genes. *J Bacteriol* **171**: 5763–5767.
- Fuller, N. J., Marie, M. D., Partensky, F., Vulot, D., Post, A. F., and Scanlan, D. J. (2003) Clade-specific 16S ribosomal DNA oligonucleotides reveal the predominance of a single marine *Synechococcus* clade throughout a stratified water column in the Red Sea. *Appl Environ Microbiol* **69**: 2430–2443.
- Furukawa, K., Noda, N., Tsureda, S., Saito, T., Itayama, T., and Inamori, Y. (2006) Highly sensitive real-time PCR assay for quantification of toxic cyanobacteria based on microcystin synthase A gene. *J Biosci and Bioeng* **102**: 90–96.
- Gans, J., Wolinsky, M., and Dunbar, J. (2005) Computational improvements reveal great bacterial diversity and high metal toxicity in soil. *Science* **309**: 1387–1390.
- García-Martínez, J., Bescós, I., Rodríguez-Sala, J. J., and Rodríguez-Valera, F. (2001) RISSC: a novel database for ribosomal 16S–23S RNA genes spacer regions. *Nucleic Acids Res* **29**: 178–180.
- García-Pichel, F. (2000) Cyanobacteria. In: Lederberg, J. (Ed.) *Encyclopedia of Microbiology*. 2nd edn. Academic Press, San Diego, CA, USA. pp. 907–927.
- García-Pichel, F., Nübel, U., and Muyzer, G. (1998) The phylogeny of unicellular, extremely halotolerant cyanobacteria. *Arch Microbiol* **169**: 469–482.
- García-Vallvé, S., Romeu, A., and Palau, P. (2000) Horizontal gene transfer in bacterial and archaeal complete genomes. *Genome Res* **10**: 1719–1725.
- Garnier, T., Canard, B., and Cole, S. T. (1991). Cloning, mapping, and molecular characterization of the rRNA operons of *Clostridium perfringens*. *J Bacteriol* **173**: 5431–5438.
- Garrrity, G. M., and Holt, J. G. (2001) The road map to the manual. In: Boone, D. R., and Castenholz, R. W. (Eds.) *Bergey's Manual of Systematic Bacteriology*. 2nd edn. Springer-Verlag, New York, NY, USA. pp. 119–155.
- Geitler, L. (1932) Cyanophyceae. In: Kolkwitz, R. (Ed.) *Rabenhorst's Kryptogamenflora von Deutschland, Österreich und der Schweiz*, Vol 14. Akademische Verlagsgesellschaft, Leipzig, Germany. pp 1–1196.
- Gest, H. (1999) Bacterial classification and taxonomy: “a primer” for the new millennium. *Microbiology Today* **26**: 70–72.
- Gevers, D., Cohan, F. M., Lawrence, J. G., Spratt, B. G., Coenye, T., Feil, E. J., Stackebrandt, E., Van de Peer, Y., Vandamme, P., Thompson, F. L., and Swings, J. (2005) Opinion: re-evaluating prokaryotic species. *Nat Rev Microbiol* **3**: 733–739.

- Gibbons, N. E., and Murray, R. G. E. (1978) Validation of Cyanobacteriales Stanier in Gibbons and Murray 1978 as a new order of the kingdom Procaryotae Murray 1968, and of the use of neuter plural endings for Photobacteria and Scotobacteria classes nov. Gibbons and Murray 1978. Request for an opinion. *Int J Syst Bacteriol* **28**: 332–333.
- Giovannoni, S. J., Turner, S., Olsen, G. J., Barns, S., Lane, D. J., and Pace, N. R. (1988) Evolutionary relationships among cyanobacteria and green chloroplasts. *J Bacteriol* **170**: 3584–3592.
- Goericke, R., and Repeta, D. J. (1992) The pigments of *Prochlorococcus marinus*: the presence of divinyl-chlorophyll *a* and *b* in a marine prokaryote. *Limnol Oceanogr* **37**: 425–433.
- Gogarten, J. P., and Townsend, J. P. (2005) Horizontal gene transfer, genome innovation and evolution. *Nat Rev Microbiol* **3**: 679–687.
- Gogarten, J. P., Doolittle, W. F. and Lawrence, J.G. (2002) Prokaryotic evolution in light of gene transfer. *Mol Biol Evol* **19**: 2226–2238.
- Gogarten, J. P., Olendzenski, L., Hilario, E., Simon, C., and Holsinger, K. E. (1996) Dating the cenancestor of organisms. *Science* **274**: 1750–1751.
- Golubic, S. (1967) *Algenvegetation der Felsen, eine oekologische Algenstudie im dinarischen Karstgebiet (Algal Vegetation on Cliffs, an Ecological Study of Algae in the Dinaric karstic Region)*. “Binnengewasser” **23**: 1–183. Schweizerbart’sche Verlagsbuchhabdlung, Stuttgart, Germany.
- Golubic, S., and Hofmann, H. J. (1976) Comparison of Holocene and mid- Precambrian Entophysalidaceae (Cyanophyta) in stromatolitic algal mats: cell division and degradation. *J Paleontol* **50**: 1074–1082.
- Golubic, S., Sergeev, V. N., and Knoll, A. H. (1995) Mesoproterozoic *Archaeoellipsoides*: akinetes of heterocystous cyanobacteria. *Lethaia* **28**: 285–298.
- Gomont, M. (1892) Monographie des Oscillariées. *Ann Sci Nat Ser Bot* **15**: 263–368. **16**: 91–264.
- Goncalves, E. R., and Rosato, Y. B. (2002) Phylogenetic analysis of *Xanthomonas* species based upon 16S–23S rDNA intergenic spacer sequences. *Int J Syst Evol Microbiol* **52**: 355–361.
- Gotelli, N. J., and Colwell, R. K. (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecol Lett* **4**: 379–391.
- Gould, S. J., and Eldredge, N. (1993) Punctuated equilibrium comes of age. *Nature* (London) **366**: 223–227.
- Grimont, F., and Grimont, P. A. (1986) Ribosomal ribonucleic acid gene restriction patterns as potential taxonomic tools. *Ann Inst Pasteur Microbiol* **137B**: 165–175.
- Guasp, C., Moore, E. R. B., Lalucat, J., and Bennisar, A. (2000) Utility of internally transcribed 16S–23S rDNA spacer regions for the definition of *Pseudomonas stutzeri* genomovars and other *Pseudomonas* species. *Int J Syst Evol Microbiol* **50**: 1629–1639.
- Gugger, M. F., and Hoffmann, L. (2004) Polyphyly of the true branching cyanobacteria (Stigonematales). *Int J Syst Evol Microbiol* **54**: 349–357.
- Gugger, M., Lyra, C., Henriksen, P., Couté, A., Humbert, J.-F., and Sivonen, K. (2002) Phylogenetic comparison of the cyanobacterial genera *Anabaena* and *Aphanizomenon*. *Int J Syst Evol Microbiol* **52**: 1–14.
- Gupta, R. S. (1998) Protein phylogenies and signature sequences: A reappraisal of evolutionary relationships among Archaeobacteria, Eubacteria and Eukaryotes. *Microbiol Mol Biol Rev* **62**: 1435–1401
- Gürtler, V., and Stanisich, V. (1996) New approaches to typing and identification of bacteria using the 16S–23S rDNA spacer region. *Microbiology* **142**: 3–16.
- Guschin, D., Mobarry, B., Proudnikov, D., Stahl, D., Rittmann, B., and Mirzabekov, A. (1997) Oligonucleotide microchips as genosensors for determinative and environmental studies in microbiology. *Appl Environ Microbiol* **63**: 2397–2402.
- Hacker, J., and Kaper, J.B. (2000) Pathogenicity islands and the evolution of microbes. *Annu Rev Microbiol* **54**: 641–679.
- Haldane, J. B. S. (1932) *The Causes of Evolution*. Princeton University Press, Princeton, N.J. USA.
- Hanage, W. P., Fraser, C., and Spratt, B. G. (2006) Sequences, sequence clusters and bacterial species. *Phil Trans R Soc B* **361**: 1917–1927. doi: 10.1098/rstb.2006.1917
- Hao, W., and Golding, G. B. (2004) Patterns of bacterial gene movement. *Mol Biol Evol* **21**: 1294–1307.
- Hayes, P. K., and Barker, G. L. (1997) Genetic diversity within Baltic Sea populations of *Nodularia* (Cyanobacteria). *J Phycol* **33**: 919–923.
- Henson, B. J., Hesselbrock, S. M., Watson, L. E., and Barnum, S. R. (2004) Molecular phylogeny of the heterocystous cyanobacteria (Subsections IV and V) based on *nifD*. *Int J Syst Evol Microbiol* **54**: 493–497.
- Herdman, M., Janvier, J. B., Waterbury, J. B., Rippka, R., Stanier, R. Y., and Mandel, M. (1979). Deoxyribonucleic acid base composition of cyanobacteria. *J Gen Microbiol* **111**: 63–71.
- Hoffmann, L., and Castenholz, R. W. (2001) Subsection V. (Formerly Stigonematales Geitler 1925). In: Boone, D. R., and Castenholz, R. W. (Eds.) *Bergey’s Manual of Systematic Bacteriology*, 2nd edn., vol. 1, Springer-Verlag, New York, NY, USA. pp. 589–599.

- Hoffmann L., Kaštovský J., and Komárek, J. (2005) Proposal of cyanobacterial system, 2004. In: Komárek J., and Anagnostidis K. (2005): Cyanoprokaryota, 2. Teil/2nd Part: Oscillatoriales. In: Büdel B., Krienitz L., Gärtner G., and Schagerl, M. (Eds.) Süßwasserflora von Mitteleuropa 19/2, Elsevier/Spektrum, Heidelberg, Germany. pp. 657–660.
- Holben, W. E., Feris, K. P., Kettunen, A., and Apajalahti, J. H. A. (2004) GC Fractionation enhances microbial community diversity assessment and detection of minority populations of bacteria by denaturing gradient gel electrophoresis. *Appl Environ Microbiol* **70**: 2263–2270.
- Holt, J. G. (1979). International Committee on Systematic Bacteriology. Judicial Commission. Minutes of the Meeting, 3 September 1978, Munich, West Germany. *Int J Syst Bacteriol* **29**, 267–269.
- Holt, J. G., Krieg, N. R., Sneath, P. H. A., Staley, J. T., and Williams, S. T. (1994) Group 11. Oxygenic phototrophic bacteria. In: Holt, J. G. (Ed.) *Bergey's Manual of Determinative Bacteriology*, 9th edn., Williams & Wilkins, Baltimore, MD, USA. pp. 377–425.
- Honda, D., Yokota, A., and Sugiyama, J. (1999) Detection of seven major evolutionary lineages in cyanobacteria based on the 16S rRNA gene sequence analysis with new sequences of five marine *Synechococcus* strains. *J Mol Evol* **48**: 723–739.
- Horz, H., Yimga, M. T., and Liesack, W. (2001) Detection of methanotroph diversity on roots of submerged rice plants by molecular retrieval of *pmoA*, *mmoX*, *mxsF*, and 16S rRNA and ribosomal DNA, including *pmoA*-based terminal restriction fragment length polymorphism profiling. *Appl Environ Microbiol* **67**: 4177–4185.
- Hull, D. L. (1997) *Species: the units of biodiversity. The ideal species concept—and why we can't get it*. Chapman and Hall, London, UK.
- Hulton, C. S. J., Higgins, C. F., and Sharp, M. P. (1991). ERIC sequences: a novel family of repetitive elements in the genomes of *Escherichia coli*, *Salmonella typhimurium* and other enterobacteria. *Mol Microbiol* **5**: 825–834.
- Huys, G., Coopman, R., Janssen, P., and Kersters, K. (1996) High resolution genotypic analysis of the genus *Aeromonas* by AFLP fingerprinting. *Intl J Syst Bacteriol* **46**: 572–580.
- Ishida, T., Yokota, A., and Sugiyama, J. (1997) Phylogenetic relationships of filamentous cyanobacterial taxa inferred from 16S rRNA sequence divergence. *J Gen Appl Microbiol* **43**: 237–241.
- Iteman, I., Rippka, R., Tandeau de Marsac, N., and Herdman, M. (2000) Comparison of conserved structural and regulatory domains within divergent 16S rRNA–23S rRNA spacer sequences of cyanobacteria. *Microbiology* **146**: 1275–1286.
- Iteman, I., Rippka, R., Tandeau de Marsac, N., and Herdman, M. (2002) rDNA analyses of planktonic heterocystous cyanobacteria including members of the genera *Anabaenopsis* and *Cyanospira*. *Microbiology* **148**: 481–496.
- Iyer, L.M., Koonin, E.V. and Aravind, L. (2004) Evolution of bacterial RNA polymerase: implications for large-scale bacterial phylogeny, domain accretion, and horizontal gene transfer. *Gene* **335**: 73–88.
- Jain, R., Rivera, M.C., and Lake, J.A. (1999) Horizontal gene transfer among genomes: The complexity hypothesis. *Proc Natl Acad Sci USA* **96**: 3801–3806.
- Janse, I., Meima, M., Kardinaal, W. E. A., and Zwart, G. (2003) High-resolution differentiation of cyanobacteria by using rRNA-internal transcribed spacer denaturing gradient gel electrophoresis. *Appl Environ Microbiol* **69**: 6634–6643.
- Janson, S., Bergman, B., Carpenter, E. J., Giovannoni, S., and Vergin, K. 1999 Genetic analysis of natural populations of the marine diazotrophic cyanobacterium *Trichodesmium*. *FEMS Microbiol Ecol* **30**: 57–65.
- Janson, S., Siddiqui, P. J. A., Walsby, A. E., Romans, K. M., Carpenter, E. J., and Bergman, B. (1995) Cytomorphological characterization of the planktonic diazotrophic cyanobacteria *Trichodesmium* spp. from the Indian Ocean and Caribbean and Sargasso Seas. *J Phycol* **31**: 463–477.
- Janssen, P., Coopman, R., Huys, G., Swings, J., Bleeker, H., Vos, P., Zabeau, M., and Kersters, K. (1996) Evaluation of the DNA fingerprinting methods: AFLP as a new tool in bacterial taxonomy. *Microbiology* **142**: 1881–1893.
- Jaspers, E., and Overmann, K. (2004) Ecological significance of microdiversity: identical 16S rRNA gene sequences can be found in bacteria with highly divergent genomes and ecophysiologicals. *Appl Environ Microbiol* **70**: 4831–4839.
- Jungblut, A.-D., Hawes, I., Mountfort, D., Hitzfeld, B., Dietrich, D. R., Burns, B. P., and Neilan, B. A. (2005) Diversity with in cyanobacterial mat communities in variable salinity meltwater ponds of McMurdo Ice Shelf, Antarctica. *Environ Microbiol* **7**: 519–529. doi: 10.1111/j.1462-2920.2005.00717.x
- Kaneko, T., Sato, S., Kotani, H., Tanaka, A., Asamizu, E., Nakamura, Y., Miyajima, N., Hirosawa, M., Sugiura, M., Sasamoto, S., Kimura, T., Hosouchi, T., Matsuno, A., Muraki, A., Nakazaki, N., Naruo, K., Okumura, S., Shimpo, S., Takeuchi, C., Wada, T., Watanabe, A., Yamada, M., Yasuda, M., and Tabata, S. (1996) Sequence analysis of the genome of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. II. Sequence determination of the entire genome and assignment of potential protein-coding regions. *DNA Res* **3**: 109–136.
- Kardinaal, W. E. A., Janse, I., Kamst-van Agterveld, M., Meima, M., Snoek, J., Mur, L. R., Huisman, J., Zwart, G., and Visser, P. M. (2007) *Microcystis* genotype succession in relation to microcystin concentrations in freshwater lakes. *Aquat Microb Ecol* **48**: 1–12.
- Karlin, S., and Burge, C. (1995) Dinucleotide relative abundance extremes: a genomic signature. *Trends Genet* **11**: 283–290.
- Keswani, J., and Whitman, W. B. (2001) Relationship of 16S rRNA sequence similarity to DNA hybridization in prokaryotes. *Int J Syst Evol Microbiol* **51**: 667–678.

- Kim, S.-G., Rhee, S.-K., Ahn, C. Y., Ko, S.-R., Choi, G.-G., Bae, J.-W., Park, Y.-H., and Oh, H.-M. (2006) Determination of cyanobacterial diversity during algal blooms in Daechung reservoir, Korea, on the basis of *cpcBA* intergenic spacer analysis. *Appl Environ Microbiol* **72**: 3252–3258.
- Kimura, M. (1980) A simple method for estimating evolutionary rates of base substitutions through comparative studies of nucleotide sequences. *J Mol Evol* **16**: 111–120.
- Kimura, M. (1983) The neutral theory of molecular evolution. In: M. Nei and R. K. Koehn (Eds.), *Evolution of Genes and Proteins*. Sinauer Associates Inc. Publishers, Sunderland, MA, USA. pp. 208–233.
- King, J. L., and Jukes, T. H. (1969) Non-Darwinian evolution. *Science* **164**: 788–798.
- Kitts, C. L. (2001) Terminal-restriction fragment patterns: a tool for comparing microbial communities and assessing community dynamics. *Curr Issues Intest Microbiol* **2**: 17–25.
- Koizumi, Y., Kelly, J. J., Nakagawa, T., Urakawa, H., El-Fantroussi, S., Al-Muzaini, S., Fukui, M., Urushigawa, Y., and Stahl, D. A. (2002) Parallel characterization of anaerobic toluene- and ethylbenzene degrading microbial consortia by PCR-denaturing gradient gel electrophoresis, RNA-DNA membrane hybridization, and DNA microarray technology. *Appl Environ Microbiol* **68**: 3215–3225.
- Komárek, J. (2003) Problem of the taxonomic category “species” in cyanobacteria. *Arch Hydrobiol Algol Stud* **109**: 281–297.
- Komárek, J. (2005) The modern classification of Cyanoprokaryotes (cyanobacteria). *Oceanological and Hydrobiological Studies* Vol XXXIV, Supplement 3, pp. 5–17.
- Komárek, J., and Anagnostidis, K. (1986) Modern approach to the classification system of Cyanophytes. 2: Chroococcales. *Arch Hydrobiol Algol Stud* **43**: 157–226.
- Komárek, J., and Anagnostidis, K. (1989). Modern approach to the classification system of Cyanophytes 4. Nostocales. *Arch Hydrobiol Suppl* **82**: 247–345
- Komárek, J., and Kovacik, L. (1989) Trichome structure of four *Aphanizomenon* taxa (Cyanophyceae) from Czechoslovakia, with notes on the taxonomy and delimitation of the genus. *Plant Syst Evol* **164**: 47–64.
- Komárek, J., and Komárková, J. (2006) Diversity of *Aphanizomenon*-like cyanobacteria. *Czech Phycology, Olomouc* **6**: 1–32.
- Konstantinidis, K. T., and Tiedje, J. M. (2005) Genomic insights that advance the species definition for prokaryotes. *Proc Natl Acad Sci USA* **102**: 2567–2572. doi: 10.1073/pnas.0409727102
- Konstantinidis, K. T., Ramette, A., and Tiedje, J. M. (2006) The bacterial species definition in the genomic era. *Phil Trans R Soc B* **361**: 1929–1940. doi: 1098/rstb.2006.1920.
- Konstantinidis, K. T., and Tiedje, J. M. (2007) Prokaryotic taxonomy and phylogeny in the genomic era: advancements and challenges ahead. *Curr Opin Microbiol* **10**: 504–509.
- Koonin, E. V. (2009) Darwinian evolution in the light of genomics. *Nucleic Acids Res* **37**: 1011–1034.
- Kumari, N., Srivastava, A. K., Bhargava, P., and Rai, L. C. (2009) Molecular approaches towards assessment of cyanobacterial diversity. *Afr J Biotechnol* **8**: 4284–4298. <http://academicjournals.org/AJB>
- Kurmayer, R., Dittmann, E., Fastner, J., and Chorus, I. E. (2002) Diversity of microcystin genes within a population of the toxic cyanobacterium *Microcystis* spp. in Lake Wannsee (Berlin, Germany). *Microb Ecol* **43**: 107–118.
- Kwon, S. W., Park, J.-Y., Kim, J.-S., Kang, J.-W., Cho, Y.-H., Lim, C.-K., Parker, M. A., and Lee, G.-B. (2005) Phylogenetic analysis of the genera *Bradyrhizobium*, *Mesorhizobium*, *Rhizobium*, and *Sinorhizobium* on the basis of 16S rRNA gene and internally transcribed spacer region sequences. *Int J Syst Evol Microbiol* **55**: 263–270.
- Laamanen, M. J., Forsström, L., and Sivonen, K. (2002) Diversity of *Aphanizomenon flos-aquae* (cyanobacterium) populations along a Baltic Sea salinity gradient. *Appl Environ Microbiol* **68**: 5296–5303.
- Lachance, M. (1981) Genetic relatedness of heterocystous cyanobacteria by deoxyribonucleic acid-deoxyribonucleic acid reassociation. *Int J Syst Evol Microbiol* **31**: 139–147.
- Laguerre, G., Allard, M., Revoy, F., and Amarger, N. (1994) Rapid identification of rhizobia by restriction fragment length polymorphism analysis of PCR-amplified 16S rRNA genes. *Appl Environ Microbiol* **60**: 56–63.
- Laloui, W., Palinska, K. A., Rippka, R., Partensky, F., Tandeau de Marsac, N., Herdman, M., and Iteman, I. (2002) Genotyping of axenic and non-axenic isolates of the genus *Prochlorococcus* and the OMF-‘*Synechococcus*’ clade by size, sequence analysis or RFLP of the internal transcribed spacer of the ribosomal operon. *Microbiology* **148**: 453–465.
- Lane, D. J., Pace, B., Olsen, G. J., Stahl, D. A., Sogin, M. L. and Pace, N. R. (1985) Rapid determination of 16S ribosomal RNA sequences for phylogenetic analyses. *Proc Natl Acad Sci USA* **82**: 6955–6959.
- Larkin, M. A., Blackshields, G., Brown, N. P., Chenna, R., McGettigan, P. A., McWilliam, H., Valentin, F., Wallace, I. M., Wilm, A., Lopez, R., Thompson, J. D., Gibson, T. J. and Higgins, D. G. (2007) ClustalW and ClustalX version 2.0. *Bioinformatics* **23**: 2947–2948. doi:10.1093/bioinformatics/blm/04
- Lavin, P., Gómez, P., González, B., and Ulloa, O. (2008) Diversity of the marine picocyanobacteria *Prochlorococcus* and *Synechococcus* assessed by terminal restriction fragment length polymorphisms of 16S-23S rRNA internal transcribed spacer sequences. *Revista Chilena de Historia Natural* **81**: 515–531.
- Lawrence, J. G., and Ochman, H. C. (1998) Molecular archaeology of *Escherichia coli* genome. *Proc Natl Acad Sci USA* **95**: 9413–9417.

- Lebaron, P., Catala, P., Fajon, C., Joux, F., Baudart, J., and Bernard, L. (1997) A new sensitive, whole cell hybridization technique for detection of bacteria involving a biotinylated oligonucleotide probe targeting rRNA and tyramide signal amplification. *Appl Environ Microbiol* **63**: 3274–3278.
- Lehtimäki, J., Lyra, C., Suomalainen, S., Sundman, P., Rouhiainen, L., Paulin, L., Salkinoja-Salonen, M., and Sivonen, K. (2000) Characterization of *Nodularia* strains, cyanobacteria from brackish waters, by genotypic and phenotypic methods. *Int J Syst Evol Microbiol* **50**: 1043–1053.
- Li, R., Carmichael, W. W., Liu, Y., and Watanabe, M. M. (2000) Taxonomic reevaluation of *Aphanizomenon flos-aquae* NH-5 based on morphology and 16S rRNA gene sequences. *Hydrobiologia* **438**: 99–105.
- Ligon, P. J. B., Meyer, K. G., Martin, J. A., and Curtis, S. E. (1991) Nucleotide sequence of a 16S rRNA gene from *Anabaena* sp. strain PCC 7120. *Nucleic Acids Res* **19**: 4553.
- Liu, W.-T., Marsh, T. L., Cheng, H., and Forney, L. J. (1997) Characterization of microbial diversity by determining terminal restriction fragment length polymorphism of genes encoding 16S rRNA. *Appl Environ Microbiol* **63**: 4516–4522.
- Liu, W. T., Mirzabekov, A. D., and Stahl, D. A. (2001) Optimization of an oligonucleotide microchip for microbial identification studies: a non-equilibrium dissociation approach. *Environ Microbiol* **3**: 619–29.
- Liu, Z., DeSantis, T. Z., Andersen, G. L., and Knight, R. (2008) Accurate taxonomy assignments from 16S rRNA sequences produced by highly parallel pyrosequencers. *Nucleic Acids Res* **36**: 1–11. doi: 10.1093/nar/gkn491.
- Loughney, K., Lund, E., and Dahlberg, J. E. (1982) tRNA genes are found between 16s and 23s rRNA genes in *Bacillus subtilis*. *Nucleic Acids Res* **10**: 1607–1624.
- Lovell, C. R., Friez, J., Longshore, J. W., and Bagwell, C. E. (2001) Recovery and phylogenetic analysis of *nifH* sequences from diazotrophic bacteria associated with dead and above ground biomass of *Spartina alterniflora*. *Appl Environ Microbiol* **67**: 5308–5314.
- Loy, A., Lehner, A., Lee, N., Adamczyk, J., Meier, H., Ernst, J., Schleifer, K. H., and Wagner, M. (2002) Oligonucleotide microarray for 16S rRNA gene-based detection of all recognized lineages of sulfate-reducing prokaryotes in the environment. *Appl Environ Microbiol* **68**: 5064–5081.
- Lu, W. (1999) Application of molecular biological techniques to the identification of cyanobacteria. Master's thesis, Liverpool John Moores University, Liverpool, England.
- Lu, W., Evans, E. H., McColl, S. K., and Saunders, V. A. (1997) Identification of cyanobacteria by polymorphisms of PCR-amplified ribosomal DNA spacer region. *FEMS Microbiol Lett* **153**: 141–149.
- Ludwig, W., and Klenk, H. (2001) Overview: a phylogenetic backbone and taxonomic framework for procaryotic systematics, In: Boone, D. R., and Castenholz, R. W. (Eds.) *Bergey's Manual of Systematic Bacteriology*, vol. 1. Springer-Verlag, New York, NY, USA. pp. 49–65.
- Ludwig, W., Strunk, O., Westram, R., Richter, L., Meier, H., Yadukumar, Buchner, A., Lai, T., Steppi, S., Jobb, G., Förster, W., Brettske, I., Gerber, S., Ginhart, A. W., Gross, O., Grumann, S., Hermann, S., Jost, R., König, A., Liss, T., Lüßmann, R., May, M., Nonhoff, B., Reichel, B., Strehlow, R., Stamatakis, A., Stuckmann, N., Vilbig, A., Lenke, M., Ludwig, T., Bode, A., and Schleifer, K.-H. (2004) ARB: a software environment for sequence data. *Nucleic Acid Res* **32**: 1363–1371.
- Lyra, C., Hantula, J., Vainio, E., Rapala, J., Rouhiainen, L., and Sivonen, K. (1997) Characterization of cyanobacteria by SDS-PAGE of whole-cell proteins and PCR-RFLP of the 16S rRNA gene. *Arch Microbiol* **168**: 176–184.
- Lyra, C., Suomalainen, S., Gugger, M., Vezie, C., Sundman, P., Paulin, L., and Sivonen, K. (2001) Molecular characterization of planktic cyanobacteria of *Anabaena*, *Aphanizomenon*, *Microcystis* and *Planktothrix* genera. *Int J Syst Evol Microbiol* **51**: 513–526.
- Maidak, B. L., Cole, J. R., Lilburn, T. G., Parker, C. T., Jr., Saxman, P. R., Farris, R. J., Garrity, G. M., Olsen, G. J., Schmidt, T. M. and Tiedje J. M. (2001) The RDP-II (Ribosomal Database Project). *Nucleic Acids Res* **29**: 173–174.
- Maiden, M. C., Bygraves, J. A., Feil, E., Morelli, G., Russell, J. E., Urwin, R., Zhang, Q., Zhou, J., Zurth, K., Caugant, D. A., Feavers, I. M., Achtman, M., and Spratt, B. G. (1998) Multilocus sequence typing: a portable approach to the identification of clones within populations of pathogenic microorganisms. *Proc Natl Acad Sci USA* **95**: 3140–3145.
- Majer, D., Lewis, B. G., and Mithen, R. (1998) Genetic variation among field isolates of *Pyrenopeziza brassicae*. *Plant Pathol* **47**: 22–28.
- Majer, D., Mithen, R., Lewis, B. G., Vos, P., and Oliver, R. P. (1996) The use of AFLP fingerprinting for the detection of genetic variation in fungi. *Mycol Res* **100**: 1107–1111.
- Makarova, K. S., Ponomarev, V. A. and Koonin, E. V. (2001) Two C or not two C: recurrent disruption of Zn-ribbons, gene duplication, lineage-specific gene loss, and horizontal gene transfer in evolution of bacterial ribosomal proteins. *Genome Biol* **2**: RESEARCH 0033.
- Malone, T. C., Ducklow, H. W., Peele, E. R., and Pike, S. E. (1991) Picoplankton carbon flux in Chesapeake Bay. *Mar Ecol Prog Ser* **78**: 11–22.
- Manichanh, C., Chapple, C. E., Frangeul, L., Gloux, K., Guigo, R., and Dore, J. (2008) A comparison of random sequence reads versus 16S rDNA sequences for estimating the biodiversity of a metagenomic library. *Nucleic Acids Res* **36**: 5180–5188.

- Margulies, M., Egholm, M., Altman, W. E., Attiya, S., Bader, J. S., Bemben, L. A., Berka, J., Braverman, M. S., Chen, Y. J., Chen, Z., Dewell, S. B., Du, L., Fierro, J. M., Gomes, X. V., Godwin, B. C., He, W., Helgesen, S., Ho, C. H., Irzyk, G. P., Jando, S. C., Alenquer, M. L. I., Jarvie, T. P., Jirage, K. B., Kim, J.-B., Knight, J. R., Lanza, J. R., Leamon, J. H., Lefkowitz, S. M., Lei, M., Li, J., Lohman, K. L., Lu, H., Makhijani, V. B., McDade, K. E., McKenna, M. P., Myers, E. W., Nickerson, E., Nobile, J. R., Plant, R., Puc, B. P., Ronan, M. T., Roth, G. T., Sarkis, G. J., Simons, J. F., Simpson, J. W., Srinivasan, M., Tartaro, K. R., Tomasz, A., Vogt, K. A., Volkmer, G. A., Wang, S. H., Wang, Y., Weiner, M. P., Yu, P., Begley, R. F., and Rothberg, J. M. (2005) Genome sequencing in micro-fabricated high-density picolitre reactors. *Nature* (London) **437**: 376–380. doi: 10.1038/nature03959
- Marsh, T. L., Saxman, P., Cole, J., and Tiedje, J. (2000) Terminal restriction fragment length polymorphism analysis Program, a web-based research tool for microbial community analysis. *Appl Environ Microbiol* **66**: 3616–3620.
- Martin, W., and Koonin, E. V. (2006) Introns and the origin of nucleus-cytosol compartmentation. *Nature* (London) **440**: 41–45.
- Martin, W., and Muller, M. (1998) The hydrogen hypothesis for the first eukaryote. *Nature* (London) **392**: 37–41.
- Martin, W., Rujan, T., Richly, E., Hansen, A., Cornelsen, S., Lins, T., Leister, D., Stoebe, B., Hasegawa, M., and Penny, D. (2002) Evolutionary analysis of *Arabidopsis*, cyanobacterial, and chloroplast genomes reveals plastid phylogeny and thousands of cyanobacterial genes in the nucleus. *Proc Natl Acad Sci USA* **99**: 12246–12251.
- Martínez-Murcia, A. J., Acinas, S. G., and Rodríguez-Valera, F. (1995) Evaluation of prokaryotic diversity by restrictionase digestion of 16S rDNA directly amplified from hypersaline environments. *FEMS Microbiol Ecol* **17**: 247–255.
- Martiny, J. G. H., Bohannan, B. J. M., Brown, J. H., Colwell, R. K., Fuhrman, J. A., Green, J. L., Horner-Devine, M. C., Kane, M., Krumins, J. A., Kuske, C. R., Morin, P. J., Naeem, S., Ørveås, L., Reysenbach, A.-L., Smith, Val, H., and Staley, J. T. (2006) Microbial biogeography: putting microbes on the map. *Nat Rev Microbiol* **4**: 102–112. doi: 10.1038/nrmicro1341
- Massol-Deya, A. A., Odelson, D. A., Hickey, R. F., and Tiedje, J. M. (1995) Bacterial community fingerprinting of amplified 16S and 16-23S ribosomal DNA gene sequences and restriction endonuclease analysis (ARDRA). In: Akkermans, A. D. L., Elsas, J. D. V., and Bruin, F. J. D. (Eds.) *Molecular Microbial Ecology Manual*. Kluwer Academic Publishers, Dordrecht, Netherlands.
- Mayr, E. (1997) *Systematics and the Origin of Species from the Viewpoint of a Zoologist*. Columbia University Press. New York, NY, USA.
- Mazard, S., Fuller, N. J., Orcutt, K. M., Bridle, O., and Scanlan, D. J. (2004) PCR analysis and distribution of unicellular cyanobacterial diazotrophs in the Arabian Sea. *Appl Environ Microbiol* **70**: 7355–7364.
- Mazel, D., Houmard, J., Castets, A. M., and Tandeau de Marsac, N. (1990) Highly repetitive DNA sequences in cyanobacterial genomes. *J Bacteriol* **172**: 2755–2761.
- Miller, S. R., Augustine, S., Olson, T. L., Blankenship, R. E., Selker, J., and Wood, A. M. (2005) Discovery of a free-living chlorophyll *d*-producing cyanobacterium with a hybrid proteobacterial/cyanobacterial small-subunit rRNA gene. *Proc Natl Acad Sci USA* **102**: 850–855.
- Moeseneder, M. M., Arrieta, J. M., Muyzer, G., Winter, C., and Herndl, G. J. (1999) Optimization of terminal restriction fragment length polymorphism analysis for complex marine bacterioplankton communities and comparison with denaturing gradient gel electrophoresis. *Appl Environ Microbiol* **65**: 3518–3525.
- Moeseneder, M. M., Winter, C., and Herndl, G. J. (2001) Horizontal and vertical complexity of attached and free-living bacteria of the Eastern Mediterranean Sea determined by 16S rDNA and 16S rRNA fingerprints. *Limnol Oceanogr* **46**: 95–107.
- Moffitt, M. C., Blackburn, S. I., and Neilan, B. A. (2001) rRNA sequences reflect the ecophysiology and define the toxic cyanobacteria of the genus *Nodularia*. *Int J Syst Evol Microbiol* **51**: 505–512.
- Moore, L. R., and Chisholm, S. W. (1999) Photophysiology of the marine cyanobacterium *Prochlorococcus*: ecotypic differences among cultured isolates. *Limnol Oceanogr* **44**: 628–638.
- Moore, L. R., Rocap, G., and Chisholm, S. W. (1998) Physiology and molecular phylogeny of coexisting *Prochlorococcus* ecotypes. *Nature* (London) **393**: 464–467.
- Moreira, D., and Philippe, H. (2000) Molecular phylogeny: pitfalls and progress. *J Theor Biol* **3**: 9–16.
- Morgan, E. A., Ikemura, T., and Nomura, M. (1977) Identification of spacer tRNA genes in individual ribosomal RNA transcription units of *Escherichia coli*. *Proc Natl Acad Sci USA* **74**: 2710–2714.
- Moyer, C. L., Dobbs, F. C., and Karl, D. M. (1994) Estimation of diversity and community structure through restriction fragment length polymorphism distribution analysis of bacterial 16S rRNA genes from a microbial mat at an active, hydrothermal vent system, Loihi seamount, Hawaii. *Appl Environ Microbiol* **60**: 871–879.
- Murray, R. G. E., and Schleifer, K. H. (1994) Taxonomic notes: a proposal for recording the properties of putative taxa of procaryotes. *Int J Syst Bacteriol* **44**: 174–176.
- Muyzer, G. (1999) DGGE/TGGE: a method for identifying genes from natural ecosystems. *Curr Opin Microbiol* **2**: 317–322.
- Muyzer, G., de Waal, E. C., and Uitterlinden, A. G. (1993) Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction-amplified genes coding for 16S rRNA. *Appl Environ Microbiol* **59**: 695–700.

- Muyzer, G., Teske, A., and Wirsén, C. O. (1995) Phylogenetic relationships of *Thiomicrospira* species and their identification in deep-sea hydrothermal vent samples by denaturing gradient gel electrophoresis of 16S rDNA fragments. *Arch Microbiol* **164**: 165–172.
- Myers, J. L., Sekar, R., and Richardson, L. L. (2007) Molecular detection and ecological significance of the cyanobacterial genera *Geitlerinema* and *Leptolyngbya* in Blackband disease of corals. *Appl Environ Microbiol* **73**: 5173–5182.
- Nakamura, Y., Itoh, T., Matsuda, H., and Gojobori, T. (2004) Biased biological functions of horizontally transferred genes in prokaryotic genomes. *Nat Genet* **36**: 760–766.
- Nakatsu, C. H. (2007) Soil microbial community analysis using denaturing gradient gel electrophoresis. *Soil Sci Soc Am J* **71**: 562–571.
- Navarro, E., Simonet, P., Normand, P., and Bardin, R. (1992) Characterization of natural populations of *Nitrobacter* spp. using PCR/RFLP analysis of the ribosomal intergenic spacer. *Arch Microbiol* **157**: 107–115.
- Nei, M. (1983) Genetic polymorphism and the role of mutation in evolution. In: Koehn, P. K., and Nei, M. (Eds.) *Evolution of Genes and Proteins*. Sinauer Associates Inc. Publishers, Sunderland, MA, USA. pp. 165–190.
- Nei, M. (1984) Genetic polymorphism and neomutationism. In: Mani, G. S. (Ed.) *Evolutionary Dynamics of Genetic Diversity*. Springer-Verlag, New York, NY, USA. pp. 214–241.
- Nei, M. (1987) *Molecular Evolutionary Genetics*. Columbia University Press, New York, NY, USA.
- Nei, M. (2005) Selectionism and neutralism in molecular evolution. *Mol Biol* **22**: 2318–2342. doi: 10.1093/molbev/msi242
- Nei, M., and Kumar, S. (2000) *Molecular Evolution and Phylogenetics*. Oxford University Press, New York, NY, USA. pp. 333
- Nei, M., and Rooney, A. P. (2005) Concerted and birth-and-death evolution of multigene families. *Annu Rev Genet* **39**: 121–152.
- Neilan, B. A., Jacobs, D., and Goodman, A. E. (1995) Genetic diversity and phylogeny of toxic cyanobacteria determined by DNA polymorphisms within the phycocyanin locus. *Appl Environ Microbiol* **61**: 3875–3883.
- Neilan, B. A., Jacobs, D., Deldot, T., Blackall, L. L., Hawkins, P. R., Cox, P. T., and Goodman, A. E. (1997) Ribosomal-RNA sequences and evolutionary relationships among toxic and nontoxic cyanobacteria of the genus *Microcystis*. *Int J Syst Bacteriol* **47**: 693–697.
- Nelissen, B., De Baere, R., Wilmotte, A., and De Wachter, R. (1996) Phylogenetic relationships of nonaxenic filamentous cyanobacterial strains based on 16S rRNA sequence analysis. *J Mol Evol* **42**: 194–200.
- Nelissen, B., Wilmotte, A., Neefs, J.-M., and De Wachter, R. (1994) Phylogenetic relationships among filamentous helical cyanobacteria investigated on the basis of 16S ribosomal RNA gene sequence analysis. *Syst Appl Microbiol* **17**: 206–210.
- Nichols, J. M., Foulds, I. J., Crouch, D. H., and Carr, N. G. (1982) The diversity of cyanobacterial genomes with respect to ribosomal RNA cistrons. *J Gen Microbiol* **128**: 2739–2746.
- Nishihara, H., Miwa, H., Watanabe, M., Nagashima, M., Yagi, O., Takamura, Y. (1997) Random amplified polymorphic DNA (RAPD) analysis for discriminating genotypes of *Microcystis* cyanobacteria. *Biosci Biotechnol Biochem* **61**: 1067–1072.
- Nishizawa, T., Asayama, M., Fujii, K., Harada, K., and Shirai, M. (1999) Genetic analysis of the peptide synthetase genes for a cyclic heptapeptide microcystin in *Microcystis* spp. *J Biochem (Tokyo)* **126**: 520–529.
- Normand, P., Ponsonnet, C., Nesme, X., Neyra, M., and Simonet, P. (1996) ITS analysis of prokaryotes. In: Akkermans, A. D. L., van Elsas, J. D., and de Bruijn, F. J. (Eds.) *Molecular Microbial Ecology Manual*, vol. 3.4.5. Kluwer Academic Publishers, Dordrecht, Netherlands. p. 1–12.
- Nübel, U., De Baere, R., Wilmotte, A., and De Wachter, R. (1996) Phylogenetic relationships of nonaxenic filamentous cyanobacterial strains based on the 16S rRNA sequence analysis. *J Mol Evol* **42**: 194–200.
- Nübel, U., Garcia-Pichel, F., and Muyzer, G. (1997) PCR primers to amplify 16S rRNA genes from cyanobacteria. *Appl Environ Microbiol* **63**: 3327–3332.
- Oberholster, P. J., Botha, A.-M., Muller, K., and Cloete, T. E. (2005) Assessment of the genetic diversity of geographically unrelated *Microcystis aeruginosa* strains using amplified fragment length polymorphisms (AFLPs). *Afr J Biotechnol* **4**: 389–399.
- Ochman, H., and Moran, N. A. (2001) Genes lost and genes found: evolution of bacterial pathogenesis and symbiosis. *Science* **292**: 1096–1099.
- Ochman, H., Lawrence, J. G., and Groisman, E. A. (2000) Lateral gene transfer and the nature of bacterial innovation. *Nature (London)* **405**: 299–304.
- Ojaimi, C., Davidson, B. E., Saint Girons, I., and Old, I. G. (1994) Conservation of gene arrangement and an unusual organization of rRNA genes in the linear chromosomes of the Lyme disease spirochaetes *Borrelia burgdorferi*, *B. garinii*, and *B. afzelii*. *Microbiology* **140**: 2931–2940.
- Olsen, G. J., Matsuda, H., Hagstrom, R. and Overbeek, R. (1994) FastDNAm1: a tool for construction of phylogenetic trees of DNA sequences using maximum likelihood. *Comput Appl Biosci* **10**: 41–48.
- Orcutt, K. M., Rasmussen, U., Webb, E. A., Waterbury, J. B., Gundersen, K., and Bergman, B. (2002) Characterization of *Trichodesmium* spp. by genetic techniques. *Appl Environ Microbiol* **68**: 2236–2245.

- Oren, A. (2004) A proposal for further integration of the cyanobacteria under the bacteriological code. *Int J Syst Evol Microbiol* **54**: 1895–1902.
- Oren, A. (2011) Cyanobacterial systematic and nomenclature as featured in the *International Bulletin of Bacteriological Nomenclature and Taxonomy/International Journal of Systematic Bacteriology/International Journal of Systematic and Evolutionary Microbiology*. *Int J Syst Evol Microbiol* **61**: 10–15.
- Oren, A., and Tindall, B. J. (2005) Nomenclature of the cyanophyta/cyanobacteria/cyanoprokaryotes under the international code of nomenclature of prokaryotes. *Arch Hydrobiol Algol Stud* **117**: 39–52.
- Osborn, A. M., Moore, E. R. B., and Timmis, K. N. (2000) An evaluation of terminal-restriction fragment length polymorphism (T-RFLP) analysis for the study of microbial structure and dynamics. *Environ Microbiol* **2**: 39–50.
- Otsuka, S., Suda, S., Li, R., Matsumoto, S., and Watanabe, M. M. (2000) Morphological variability of colonies of *Microcystis* morphospecies in culture. *J Gen Appl Microbiol* **46**: 39–50.
- Otsuka, S., Suda, S., Li, R., Watanabe, M., Oyaizu, H., Matsumoto, S., and Watanabe, M. M. (1998) 16S rDNA sequences and phylogenetic analyses of *Microcystis* strains with and without phycoerythrin. *FEMS Microbiol Lett* **164**: 119–124.
- Otsuka, S., Suda, S., Li, R., Watanabe, M., Oyaizu, H., Matsumoto, S., and Watanabe, M. M. (1999) Phylogenetic relationships between toxic and non-toxic strains of the genus *Microcystis* based on 16S to 23S internal transcribed spacer sequence. *FEMS Microbiol Lett* **172**: 15–21.
- Otsuka, S., Suda, S., Shibata, S., Oyaizu, H., Matsumoto, S., and Watanabe, M. M. (2001) A proposal for the unification of five species of the cyanobacterial genus *Microcystis* Kützinger ex Lemmermann 1907 under the Rules of the Bacteriological Code. *Int J Syst Evol Microbiol* **51**: 873–879.
- Page, R. W., Jackson, M. J., and Krassay, A. A. (2000) Constraining sequence stratigraphy in north Australian basins: SHRIMP U–Pb zircon geochronology between Mt Isa and McArthur River. *Aus J Earth Sci* **47**: 431–459.
- Palenik, B., and Swift, H. (1996) Cyanobacterial evolution and prochlorophyte diversity as seen in DNA-dependent RNA polymerase gene sequences. *J Phycol* **32**: 638–646.
- Palinska, K. A., Liesack, W., Rhiel, E. and Krumbein, W. E. (1996) Phenotype variability of identical genotypes: the need for a combined approach in cyanobacterial taxonomy demonstrated on *Merismopedia*-like isolates. *Arch Microbiol* **166**: 224–233.
- Palinska, K. A., Thomasius, C. F., Marquardt, J., and Golubic, S. (2006) Phylogenetic evaluation of cyanobacteria preserved as historic herbarium exsiccata. *Int J Syst Evol Microbiol* **56**: 2253–2263.
- Palmer, C., Bik, E. M., Eisen, M. B., Eckburg, P. B., Sana, T. R., Wolber, P. K., Relman, D. A., and Brown, P. O. (2006) Rapid quantitative profiling of complex microbial populations. *Nucleic Acids Res* **34**: e5 doi: 10.1093/nar/gnj007
- Pedros-Alíó, C. (2006) Marine microbial diversity: can it be determined? *Trends Microbiol* **14**: 257–263.
- Pei, A., Nossa, C. W., Chokshi, P., Blaser, M. J., Yang, L., Rosmarin, D. M., and Pei, Z. (2009) Diversity of 23S rRNA genes within individual prokaryotic genomes. *PLoS ONE* **4**: e5437. doi: 10.1371/journal.pone.0005437
- Pei, A. Y., Oberdorf, W. E., Nossam C. W., Agarwal, A., Chokshi, P., Gerz, E. A., Lee, P., Yang, L., Poles, M., Brown, S. M., Sotero, S., DeSantis, T., Brodie, E., Nelson, K., and Pei, Z. (2010) Diversity of 16S rRNA genes within individual prokaryotic genomes. *Appl Environ Microbiol* **76**: 3886–3897. doi: 10.1128/AEM.02953-09
- Perna, N. T., Plunkett, G. 3rd, Burland, V., Mau, B., Glasner, J. D., Rose, D. J., Mayhew, G. F., Evans, P. S., Gregor, J., Kirkpatrick, H. A. *et al.* (2001) Genome sequence of enterohaemorrhagic *Escherichia coli* O157: H7. *Nature* (London) **409**: 529–533.
- Persson, P.-E. (1996) Cyanobacteria and off-flavours. *Phycologia* **35**: 168–171.
- Perumal, G. M., Ganesan, V., and Anand, N. (2009) Identification and phylogenetic analysis of filamentous cyanobacteria using random amplified polymorphic DNA (RAPD) finger printing. *Afr J Biotechnol* **8**: 974–978.
- Pinevich, A. V. (2008) The paradoxes of biodiversity, phylogeny and taxonomy of cyanobacteria. *Moscow Univ Biol Sci Bull* **63**: 21–24.
- Postius, C., and Ernst, A. (1999) Mechanisms of dominance: coexistence of picocyanobacterial genotypes in a freshwater ecosystem. *Arch Microbiol* **172**: 69–75.
- Postius, C., Ernst, A., Kenter, U., and Böger, P. (1996) Persistence and genetic diversity among strains of phycoerythrin-rich cyanobacteria from the picoplankton of Lake Constance. *J Plankton Res* **18**: 1159–1166.
- Prabina, B. J., Kumar, K., and Kannaiyan, S. (2005) DNA amplification fingerprinting as a tool for checking genetic purity of strains in the cyanobacterial inoculum. *World J Microbiol Biotechnol* **21**: 629–634. doi:10.1007/s11274-004-3566-5
- Rajaniemi, P., Hrouzek, P., Kaštovská, K., Willame, R., Rantala, A., Hoffmann, L., Komárek, J., and Sivonen, K. (2005) Phylogenetic and morphological evaluation of genera *Anabaena*, *Aphanizomenon*, *Trichormus* and *Nostoc* (Nostocales, Cyanobacteria). *Int J Syst Evol Microbiol* **55**: 11–26.
- Ramakrishnan, B., Lueders, T., Conrad, R., and Friedrich, M. (2000) Effect of soil aggregate size on methanogenesis and archaeal community structure in anoxic rice field soil. *FEMS Microbiol Ecol* **32**: 261–270.
- Rasmussen, U., and Svenning, M. M. (1998) Fingerprinting of cyanobacteria based on PCR with primers derived from short and long tandemly repeated repetitive sequences. *Appl Environ Microbiol* **64**: 265–272.

- Rastogi, R., Wu, M., Das Gupta, I., and Fox, G. E. (2009) Visualization of ribosomal RNA operon copy number distribution. *BMC Microbiol* **9**: 208. doi: 10.1186/1471-2180-9-208
- Rippka, R. (1988) Recognition and identification of cyanobacteria. *Methods Enzymol* **167**: 28–67.
- Rippka, R., and Cohen-Bazire, G. (1983) The Cyanobacteriales: a legitimate order based on the type strain *Cyanobacterium stanieri*? *Ann Microbiol* (Paris) **134**: 21–36.
- Rippka, R., and Herdman, H. (1992) *Pasteur Culture Collection of Cyanobacteria: Catalogue and Taxonomic Handbook. I. Catalogue of Strains*. Institut Pasteur, Paris.
- Rippka, R., Deruelles, J., Waterbury, J. B., Herdman, M., and Stanier, R. Y. (1979) Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *J Gen Microbiol* **111**: 1–61.
- Robertson, B. R., Tezuka, N., and Watanabe, M. M. (2001) Phylogenetic analyses of *Synechococcus* strains (cyanobacteria) using sequences of 16S rDNA and part of the phycocyanin operon reveal multiple evolutionary lines and reflect phycobilin content. *Int J Syst Evol Microbiol* **51**: 861–871.
- Robinson, N. J., Robinson, P. J., Gupta, A., Bleasby, A. J., Whitton, B. A., and Morby, A. P. (1995) Singular over-representation of an octameric palindrome, HIP1, in DNA from many cyanobacteria. *Nucleic Acids Res* **23**: 729–735.
- Rocap, G., Moore, L. R., and Chisholm, S. W. (1999) Molecular phylogeny of *Prochlorococcus* ecotypes, In: Charpy, L., and Larkum, A. W. D. (Eds.) *Marine Cyanobacteria*. Bulletin de l'Institut Océanographique, Monaco, Special Issue 19. pp. 107–116.
- Rocap, G., Distel, D. L., Waterbury, J. B., and Chisholm, S. W. (2002) Resolution of *Prochlorococcus* and *Synechococcus* ecotypes by using 16S–23S ribosomal DNA internal transcribed spacer sequences. *Appl Environ Microbiol* **68**: 1180–1191.
- Rosselló-Móra, R., and Amann, R. (2001) The species concept for prokaryotes. *FEMS Microbiol Rev* **25**: 39–67. doi: 10.1111/j.1574-6976.2001.tb00571.x
- Rost, B., and Sander, C. (1996) Bridging the protein sequence-structure gap by structure predictions. *Annu Rev Biophys Biomol Struct* **25**: 113–136.
- Rouhiainen, L., Sivonen, K., Buikema, W., and Haselkorn, R. (1995) Characterization of toxin-producing cyanobacteria by using an oligonucleotide probe containing a tandemly repeated heptamer. *J Bacteriol* **177**: 6021–6026.
- Rudi, K., Skulberg, O. M., and Jakobsen, K. S. (1998) Evolution of cyanobacteria by exchange of genetic material among phyletically related strains. *J Bacteriol* **180**: 3453–3461.
- Rudi, K., Skulberg, O. M., Skulberg, R., and Jakobsen, K. S. (2000) Application of sequence-specific labeled 16S rRNA gene oligonucleotide probes for genetic profiling of cyanobacterial abundance and diversity by array hybridization. *Appl Environ Microbiol* **66**: 4004–4011.
- Saitou, W., and Nei, M. (1987) The neighbor-joining method: A new method for reconstructing phylogenetic trees. *Mol Biol Evol* **4**: 406–425.
- Saker, M. L., and Neilan, B. A. (2001) Varied diazotrophies, morphologies and toxicities of genetically similar isolates of *Cylindrospermopsis raciborskii* (Nostocales, Cyanophyceae) from Northern Australia. *Appl Environ Microbiol* **67**: 1839–1845.
- Sarma, T. A. (1981) Life cycle of *Stichosiphon indica* in cultures. *New Phytol* **88**: 103–110.
- Scheldeman, P. B., Baurain, D., Bouhy, R., Scott, M., Muhling, M., Whitton, B. A., Belay, A., and Wilmotte, A. (1999) *Arthrospira* ('*Spirulina*') strains from four continents are resolved into only two clusters, based on amplified ribosomal DNA restriction analysis of the internally transcribed spacer. *FEMS Microbiol Lett* **172**: 213–222.
- Schmidt, T. M., DeLong, E. F., and Pace, N. R. (1991) Analysis of marine picoplankton community by 16S rRNA gene cloning and sequencing. *J Bacteriol* **173**: 4371–4378.
- Schönhuber, W., Fuchs, B., Juretschko, S., and Amann, R. (1997) Improved sensitivity of whole-cell hybridization by the combination of horseradish peroxidase-labeled oligonucleotides and tyramide signal amplification. *Appl Environ Microbiol* **63**: 3268–3273.
- Schönhuber, W., Zarda, B., Eix, S., Rippka, R., Herdman, M., Ludwig, W., and Amann, R. (1999) *In situ* identification of cyanobacteria with Horseradish peroxidase-labeled, rRNA-targeted oligonucleotide probes. *Appl Environ Microbiol* **65**: 1259–1267.
- Schopf, J. W. (1968) Microflora of the Bitter Springs Formation, Late Precambrian, Central Australia. *J Paleontol* **42**: 651–688.
- Schopf, J. W. (1993) Microfossils of the Early Archaean Apex Chert: New Evidence of the Antiquity of Life. *Science* **260**: 640–646.
- Schopf, J. W. and Walter, M. R. (1983) Archean microfossils, new evidence of ancient microbes In: Schopf, J. W. (Ed.) *Earth's Earliest Biosphere: its Origin and Evolution*. Princeton University Press, Princeton, NJ, USA. pp 214–239.
- Schopf, J. W., Kudryavtsev, A. B., Agresti, D. G., Wdowiak, T. J., and Czaja, A. D. (2002) Laser-Raman imagery of Earth's earliest fossils. *Nature* (London) **416**: 73–76
- Sen, S., and Nilsson, L. (1998) Molecular dynamics of duplex systems involving PNA: structural and dynamical consequences of the nucleic acid backbone. *J Am Chem Soc* **120**: 619–631.
- Sergeev, V. N. (2009) The distribution of microfossil assemblages in Proterozoic rocks. *Precambrian Res* **173**: 212–222.

- Seo, P.-S., and Yokota, A. (2003) The phylogenetic relationships of cyanobacteria inferred from 16S rRNA, *gyrB*, *rpoC1* and *rpoD1* gene sequences. *J Gen Appl Microbiol* **49**: 191–203.
- Sessitsch, A., Weilharter, A., Gerzabek, M. H., Kirchmann, H., and Kandeler, E. (2001) Microbial population structures in soil particle size fractions of a long-term fertilizer field experiment. *Appl Environ Microbiol* **67**: 4215–4224.
- Sharma, M., and Shukla, Y. (2009) The evolution and distribution of life in the Precambrian eon-Global perspective of the Indian record. *J Biosci* **34**: 765–776. <http://www.ias.ac.in/jbiosci>
- Sharples, G. J., and Lloyd, R. G. (1990) A novel repeated sequence located in the intergenic regions of bacterial chromosomes. *Nucleic Acids Res* **18**: 6503–6508.
- Sheldon, P. R. (1987) Parallel gradualistic evolution of Ordovician trilobites. *Nature* (London) **330**: 561–563.
- Sigler, W.V., Bachofen, R., and Zeger, J. (2003) Molecular characterization of endolithic cyanobacteria inhabiting exposed dolomite in central Switzerland. *Environ Microbiol* **5**: 618–627.
- Skulberg O. M., and Skulberg, R. (1985) Planktic species of *Oscillatoria* (cyanophyceae) from Norway. *Arch Hydrobiol [Suppl 71, 1/2] Algol Stud* **38/39**: 157–174.
- Small, J., Call, D. R., Brockman, F. J., Straub, T. M., and Chandler, D. P. (2001) Direct detection of 16S rRNA in soil extracts by using oligonucleotide microarrays. *Appl Environ Microbiol* **67**: 4708–4716.
- Smith, J. K., Parry, J. D., Day, J. G., and Smith, R. J. (1998) A PCR technique based on HIP1 interspersed repetitive sequence distinguishes cyanobacterial species and strains. *Microbiology* **144**: 2791–2801.
- Sompong, U., Anuntalabhochai, S., Cutler, R. W., Castenholz, R. W., and Peerapornpisal, Y. (2008) Morphological and phylogenetic diversity of cyanobacterial populations in six hot springs of Thailand. *ScienceAsia* **34**: 153–162.
- Song, J., Lee, S.-C., Kang, J. W., Baek, H.-J., and Suh, J.-W. (2004) Phylogenetic analysis of *Streptomyces* spp. isolated from potato scab lesions in Korea on the basis of 16S rRNA gene and 16S-23S rDNA internally transcribed spacer sequences. *Int J Syst Evol Microbiol* **54**: 203–209.
- Song, T., Martensson, L., Eriksson, T., Zheng, W., and Rasmussen, V. (2005) Biodiversity and seasonal variation of the cyanobacterial assemblage in a rice paddy field in Fujian, China. *FEMS Microbiol Ecol* **54**: 131–140.
- Sorek R, Zhu, Y., Creevey, C. J., Francino, M. P., Bork, P., and Rubin, E. M. (2007) Genome-wide experimental determination of barriers to horizontal gene transfer. *Science* **318**: 1449–1452.
- Soria-Carrasco, V., and Castresana, J. (2008) Estimation of phylogenetic inconsistencies in the three domains of life. *Mol Biol Evol* **25**: 2319–2329.
- Sournia, A. (1968) La cyanophyceae *Oscillatoria* (*Trichodesmium*) dans le plancton marin. *Nova Hedwigia* **15**: 1–12.
- Srivastava, A. K., and Schlessinger, D. (1990) Mechanism and regulation of bacterial ribosomal RNA processing. *Annu Rev Microbiol* **44**: 105–129.
- Srivastava, A. K., Bhargava, P., Kumar, A., Rai, L. C., and Neilan, B. A. (2009) Molecular characterization and the effect of salinity on cyanobacterial diversity in the ricefields of Eastern Uttar Pradesh. *Saline Systems* **5**: 4 doi: 10.1186/1746-1448-5-4; <http://www.salinesystems.org/content/5/1/4>.
- Srivastava, P. (2005) Vindhyan akinetes: An indicator of Mesoproterozoic biospheric evolution. *Orig Life Evol Biosph* **33**: 175–183.
- Stackebrandt, E., and Goebel, B. M. (1994) Taxonomic note: a place for DNA-DNA re-association and 16S rRNA sequence analysis in the present species definition in Bacteriology. *Int J Syst Bacteriol* **44**: 846–849.
- Stackebrandt, E., and Ebers J. (2006) Taxonomic parameters revisited: tarnished gold standards. *Microbiol Today* **8**: 6–9.
- Staley, J. T. (1999) Bacterial biodiversity: a time for place. *ASM News* **10**: 1–6.
- Staley, J. T. (2006) The bacterial species dilemma and the genomic-phylogenetic species concept. *Phil Trans R Soc B* **361**: 1899–1909.
- Staley, J. T., and Gosink, J. J. (1999) Poles apart: biodiversity and biogeography of polar sea ice bacteria. *Annu Rev Microbiol* **53**: 189–215. doi: 10.1146/annurev.micro.53.1.189
- Stanier, R.Y., Sistrom, W. R., Hansen, T. A., Whitton, B. A., Castenholz, R. W., Pfennig, N., Gorlenko, V. N., Kondratieva, E. N., Eimhjellen, K. E., Whittenbury, R., Gherna, R. L., and Trüper, H. G. (1978) Proposal to place nomenclature of the cyanobacteria (blue-green algae) under the rules of the International Code of Nomenclature of Bacteria. *Int J Syst Bacteriol* **28**: 335–336.
- Stoesser, G., Baker, W., van den Broek, A., Camon, E., Garcia-Pastor, M., Kanz, C., Kulikova, T., Leinonen, R., Lin, Q., Lombard, V., Lopez, R., Parkinson, H. *et al.* (2002) The EMBL nucleotide sequence database. *Nucleic Acids Res* **30**: 21–26.
- Stulp, B. K. (1983) Morphological and molecular approaches to the taxonomy of the genus *Anabaena* (Cyanophyceae, Cyanobacteria). Drukkerij van Denderen B. V., Groningen, Germany.
- Suda, S., Watanabe, M. M., Otsuka, S., Mahakahant, A., Yongmanitchai, W., Nopartnaraporn, N., Liu, Y., and Day, J. G. (2002) Taxonomic revision of waterbloom forming species of Oscillatoriid cyanobacteria. *Int J Syst Evol Microbiol* **52**: 1577–1595.

- Swofford, D. L., Olsen, G. J., Waddell, P. J., and Hillis, D. M. (1996) Phylogenetic inference. In: Hillis, D. M., Moritz, C., and Mable, B. K. (Eds.) *Molecular Systematics*. Sinauer, Sunderland, Massachusetts, USA. pp 407–509.
- Tanabe, Y., Kasai, F., and Watanabe, M. M. (2007) Multilocus sequence typing (MLST) reveals high genetic diversity and clonal population structure of the toxic cyanobacterium *Microcystis aeruginosa*. *Microbiology* **153**: 3695–3703.
- Taton, A., Grubisic, S., Brambilla, E., De Wit, R., and Wilmette, A. (2003) Cyanobacterial diversity in natural and artificial microbial mats of Lake Fryxell (McMurdo Dry Valleys, Antarctica): a morphological and molecular approach. *Appl Environ Microbiol* **69**: 5157–5169.
- Tettelin, H., Masignani, V., Cieslewicz, M. J., Donati, C., Medini, D., Ward, N. L., Angiuoli, S. V., Crabtree, J., Jones, A. L., Durkin, A. S., DeBoy, R. T., Davidsen, T. M., Mora, M., Scarselli, M., Ros, I. M., Peterson, J. D., Hauser, C. R., Sundaram, J. P., Nelson, W. C., Madupu, R., Brinkae, L. M., Dodson, R. J., Rosovitz, M. J., Sullivan, S. A., Daugherty, S. C., Haft, D. H., Selengut, J., Gwinn, G. L., Zhou, L., Zafar, N., Khouri, H., Radune, D., Dimitrov, G., Watkins, K., O'Connor, K. J. B., Smith, S., Utterback, T. R., White, O., Rubens, C. E., Grandi, G., Madoff, L. C., Kasper, D. L., Telford, J. L., Wessels, M. R., Rappuoli, R., and Fraser, C. M. (2005) Genome analysis of multiple pathogenic isolates of *Streptococcus agalactiae*: implications for the microbial 'pangenome'. *Proc Natl Acad Sci USA* **102**: 13950–13955.
- Thacker, R. W., and Paul, V. J. (2004) Morphological, chemical and genetic diversity of tropical marine cyanobacteria *Lyngbya* spp. and *Symploca* spp. (Oscillatoriales) *Appl Environ Microbiol* **70**: 3305–3312.
- Thompson, J. D., Higgins, D. G. and Gibson, D. J. (1994) CLUSTAL W: improving the sensitivity of progressive multiple sequence alignment. *Comput Appl Biosci* **8**: 189–191.
- Thuret, G. (1875) Essay de classification des Nostochinées. *Ann Sci Nat* **6**: 372–382.
- Tiedje, J. M., Asuming-Brempong, S., Nusslein, K., Marsh, T. L., and Flynn, S. J. (1999) Opening the black box of soil microbial diversity. *Appl Soil Ecol* **13**: 109–122.
- Tillett, D., Parker, D. L., and Neilan, B. A. (2001) Detection of toxigenicity by a probe for the microcystin synthetase gene (*mcyA*) of the cyanobacterial genus *Microcystis*: comparison of toxicities with 16S rRNA and phycocyanin operon (phycocyanin intergenic spacer) phylogenies. *Appl Environ Microbiol* **67**: 2810–2818.
- Tindall, B. J., Rosselló-Móra, R., Busse, H.-J., Ludwig, W., and Kämpfer, P. (2010). Notes on the characterization of prokaryote strains for taxonomic purposes. *Int J Syst Evol Microbiol* **60**: 249–266.
- Tomioka, N., and Sugiura, M. (1984) Nucleotide sequence of the 16S-23S spacer region in the *rnmA* operon from a blue-green alga, *Anacystis nidulans*. *Mol Gen Genet* **193**: 427–430.
- Tomioka, N., Shinozaki, K. and Sugiura, M. (1981) Molecular cloning and characterization of ribosomal RNA genes from a blue-green algae, *Anacystis nidulans*. *Mol Gen Genet* **184**: 359–363.
- Tomitani, A., Knoll, A. H., Cavanaugh, C. M., and Ohno, T. (2006) The evolutionary diversification of cyanobacteria: Molecular phylogenetic and palaeontological perspectives. *Proc Natl Acad Sci USA* **103**: 5442–5447.
- Tringe, S., von Mering, C., Kobayashi, A., Salamov, A. A., Chen, K., Chang, H. W., Podar, M., Short, J. M., Mathur, A. J., Detter, J. C., Bork, P., Hugenholtz, P., and Rubin, E. M. (2005) Comparative metagenomics of microbial communities. *Science* **308**: 554–557.
- Turner, S. (1997) Molecular systematics of oxygenic photosynthetic bacteria. *Plant Syst Evol* **11**: 13–52.
- Turner, S., Huang, T.-C., and Chaw, S.-M. (2001) Molecular phylogeny of nitrogen fixing unicellular forms. *Bot Bull Acad Sin* **42**: 181–186.
- Turner, S., Pryer, K.M., Miao, V.P., and Palmer, J.D. (1999) Investigating deep phylogenetic relationships among cyanobacteria and plastids by small subunit rRNA sequence analysis. *J Eukaryot Microbiol* **46**: 327–338.
- Tyson, G. W., Chapman, J., Hugenholtz, P., Allen, E. E., Ram, R. J., Richardson, P. M., Solovyev, V. V., Rubin, E. M., Rokhsar, D. S., and Banfield, J. F. (2004) Community structure and metabolism through reconstruction of microbial genomes from the environment. *Nature (London)* **428**: 37–43.
- Urbach, E., Scanlan, D. J., Distel, D. L., Waterbury, J. B., and Chisholm, S. W. (1998) Rapid diversification of marine picophytoplankton with dissimilar light-harvesting structures inferred from sequences of *Prochlorococcus* and *Synechococcus* (cyanobacteria). *J Mol Evol* **46**: 188–201.
- Valério, E., Chambel, L., Paulino, S., Fario, N., Pereira, P., and Tenreiro, R. (2009) Molecular identification, typing and traceability of cyanobacteria from freshwater reservoir. *Microbiology* **155**: 642–656.
- Van Gijlswijk, R. P. M., Wiegant, J., Raap, A. K., and Tanke, H. J. (1996) Improved localization of fluorescent tyramides for *in situ* fluorescence hybridization using dextran sulfate and polyvinyl alcohol. *J Histochem Cytochem* **44**: 389–392.
- Venter, J. C., Remington, K., Heidelberg, J. F., Halpern, A. L., Rusch, D., Eisen, J. A., Wu, D., Paulsen, I., Nelson, K. E., Nelson, W., Fouts, D. E., Levy, S., Knap, A. H., Lomas, M. W., Neelson, K., White, O., Peterson, J., Hoffman, J., Parsons, R., Baden-Tillson, H., Pfannkoch, C., Rogers, Y.-H., and Smith, H. O. (2004) Environmental genome shotgun sequencing of the Sargasso Sea. *Science* **304**: 66–74.
- Vincent, W. F., Bowman, J. P., Rankin, L. M., and McMeekin, T. A. (1999) Phylogenetic diversity of picocyanobacteria in Arctic and Antarctic ecosystems. In: Bell, C. R., Brylinsky, M., and Johnson-Green, P. (Eds.) *Microbial Biosystems: New Frontiers*: Atlantic Canada Society for Microbial Ecology, Halifax, Nova Scotia, Canada.

- Vinuesa, P., Rademaker, J. L. W., De Bruijn, F. J., and Werner, D. (1998) Genotypic characterization of *Bradyrhizobium* strains nodulating endemic woody legumes of the Canary Islands by PCR-restriction fragment length polymorphism analysis of genes encoding 16S rRNA (16S rDNA) and 16S–23S rDNA intergenic spacers, repetitive extragenic palindromic PCR genomic fingerprinting, and partial 16S rDNA sequencing. *Appl Environ Microbiol* **64**: 2096–2104.
- Vos, P., Hogers, R., Bleeker, M., Reijans, M., Van de Lee, T., Hornes, M., Frijters, A., Pot, J., Peleman, J., Kuiper, M., and Zabeau, M. (1995) AFLP: a new technique for DNA fingerprinting. *Nucleic Acids Res* **23**: 4405–4414.
- Wang, R. F., Beggs, M. L., Robertson L. H. and Cerniglia, C. E. (2002) Design and evaluation of oligonucleotide-microarray method for the detection of human intestinal bacteria in fecal samples. *FEMS Microbiol Lett* **213**: 175–182.
- Wang, R. F., Beggs, M. L., Erickson, B. D. and Cerniglia, C. E. (2004) DNA microarray analysis of predominant human intestinal bacteria in fecal samples. *Mol Cell Probes* **18**: 223–234.
- Ward, D. M., Ferris, M. J., Nold, S. C., Bateson, M. M., Kopczynski, E. D., and Ruff-Roberts, A. L. (1994) Species diversity in hot spring microbial mats as revealed by both molecular and enrichment culture approach-relationship between biodiversity and community structure. In: Stal, L. J., and Caumette, P. (Eds.) *Microbial Mats, Structure, Development and Environmental Significance* (NATO ASI Series, G.35), Springer-Verlag, Heidelberg, Germany pp. 33–44.
- Watanabe, M. (1996) Isolation, cultivation, and classification of bloom-forming *Microcystis* in Japan. In: Watanabe, M. F., Harada, K., Carmichael, W. W., and Fukui, H. (Eds.) *Toxic Microcystis*. CRC Press, Boca Raton, FL, USA pp. 13–34.
- Wayne, L. G., Brenner, D. J., Colwell, R. R., Grimont, P. A. D., Kandler, O., Krichevsky, M. I., Moore, L. H., Moore, W. E. C., Murray, R. G. E., Stackebrand, E., Starr, M. P., and Trüper, H. G. (1987) Report of the ad-hoc committee on reconciliation of approaches to bacterial systematics. *Int J Syst Bacteriol* **37**: 463–464.
- Waterbury, J. B., and Rippka, R. (1989) The order *Chroococcales*. In: Krieg, N. R., and Holt, J. B. (Eds.) *Bergey's Manual of Systematic Bacteriology*, vol. 3. Williams & Wilkins, Baltimore, MD, USA. pp. 1728–1746.
- Weiwen, Z., Tieying, S., Xiaodong B., Birgitta, B., and Ulla, R. (2002) High cyanobacterial diversity in coralloid roots of cycads revealed by PCR fingerprinting. *FEMS Microbiol Ecol* **40**: 215–222.
- Welsh, J., and McClelland, M. (1990) Finger printing of genomes using PCR with arbitrary primers. *Nucleic Acids Res* **18**: 7213–7218.
- West, N. J., and Adams, D. G. (1997) Phenotypic and genotypic comparison of symbiotic and free-living cyanobacteria from a single field site. *Appl Environ Microbiol* **63**: 4479–4484.
- West, N. J., Schönhuber, W. A., Fuller, N. J., Amann, R. I., Rippka, R., Post, A. F., and Scanlan, D. J. (2001) Closely related *Prochlorococcus* genotypes show remarkably different depth distributions in two oceanic regions as revealed by *in situ* hybridization using 16S rRNA-targeted oligonucleotides. *Microbiology* **147**: 1731–1744.
- Whitman, W. B., Coleman, D. C., and Wiebe, W. J. (1998) Prokaryotes: the unseen majority. *Proc Natl Acad Sci USA* **95**: 6578–6583.
- Whitaker, R. J. (2006) Allopatric origins of microbial species. *Phil Trans R Soc B* **361**: 1975–1984.
- Whitaker, R. J., Grogan, D. W., and Taylor, J. W. (2003) Geographic barriers isolated endemic population of hyperthermophilic archaea. *Science* **301**: 976–978. doi: 10.1126/science.1086909.
- Whitton, B. A., and Potts, M. (Eds.) (2000) Introduction to the Cyanobacteria. In: Whitton, B. A., and Potts, M. (Eds.) *The Ecology of Cyanobacteria: Their Diversity in Time and Space*. Kluwer Academic Publishers, Dordrecht, Netherlands. pp. 1–11.
- Wille, N. (1904) Die Schizophyceen der Plankton Expedition. In: Hensen, V. (Ed.) *Ergebnisse der Plankton-Expedition der Humboldt-Stiftung*. Lipsius and Tischer, Kiel, Germany.
- Willame, R., Boute, C., Grubisic, S., Komárek, J., Hoffmann, L., and Wilmotte, A. (2006) Morphological and molecular characterisation of planktonic cyanobacteria from Belgium and Luxembourg. *J Phycol* **42**: 1312–1332.
- Wilmotte, A. (1994) Molecular evolution and taxonomy of the cyanobacteria. In: Bryant, D. A. (Ed.) *The Molecular Biology of Cyanobacteria*. Kluwer Academic Publishers, Dordrecht, Netherlands. pp. 1–25.
- Wilmotte, A., and Golubic, S. (1991) Morphological and genetic criteria in the taxonomy of Cyanophyta/Cyanobacteria. *Arch Hydrobiol* **64**: 1–24.
- Wilmotte, A., and Herdman, M. (2001) Phylogenetic relationships among the cyanobacteria based on 16S rRNA sequences. In: Garrity, G. M. (Ed.) *Bergey's Manual of Systematic Bacteriology*. Springer-Verlag, New York, NY, USA. pp. 487–493.
- Wilmotte, A. M. R., and Stam, W. T. (1984) Genetic relationships among cyanobacterial strains originally designated as *Anacystis nidulans* and some other *Synechococcus* strains. *J Gen Microbiol* **130**: 2737–2740.
- Wilmotte, A., Neefs, J. M., and De Wachter, R. (1994) Evolutionary affiliation of the marine nitrogen-fixing cyanobacterium *Trichodesmium* sp. strain NIBB 1067, derived by 16S ribosomal RNA sequence analysis. *Microbiology* **140**: 2195–2164.
- Wilmotte, A., Turner, S., van der Peer, Y., and Pace, N. R. (1992) Taxonomic study of marine Oscillatorian strains (Cyanobacteria) with narrow trichomes. II. Nucleotide sequence analysis of the 16S ribosomal RNA. *J Phycol* **28**: 828–838.
- Wilson, K. M., Schembri, M. A., Baker, P. D., and Saint, C. P. (2000) Molecular characterization of the toxic cyanobacterium *Cylindrospermopsis raciborskii* and design of a species-specific PCR. *Appl Environ Microbiol* **66**: 332–338.
- Wilson, L. A., and Sharp, M. P. (2006) Enterobacterial repetitive intergenic consensus (ERIC) sequences in *Escherichia coli*: evolution and implications for ERIC-PCR. *Mol Biol Evol* **23**: 1156–1168.

- Woese, C. R. (1987) Bacterial evolution. *Microbiol Rev* **51**: 221–271.
- Woese, C. R., Kandler, O., and Wheelis, M. (1990) Towards a natural system of organisms. Proposal for the domains Archaea, Bacteria and Eucarya. *Proc Natl Acad Sci USA* **87**: 4576–4579.
- Wolf, Y. I., Rogozin, I. B., Grishin, N. V., and Koonin, E. V. (2002) Genome trees and the trees of life. *Trends Genet* **18**: 472–479.
- Worden, A. Z., Chisholm, S. W., and Binder, B. J. (2000) *In situ* hybridization of *Prochlorococcus* and *Synechococcus* (Marine cyanobacteria) spp. with rRNA-targeted peptide nucleic acid probes. *Appl Environ Microbiol* **66**: 284–289.
- Wright, S. (1931) Evolution in Mendelian populations. *Genetics* **16**: 97–159.
- Wu, Z., Shi, J., and Li, R. (2010) Unraveling molecular diversity and phylogeny of *Aphanizomenon* (Nostocales, Cyanobacteria) strains isolated from China. *J Phycol* **46**: 1048–1058.
- Wuyts, J., De Rijk, P., Van de Peer, Y., Winkelmans, T. and De Wachter, R. (2001) The European Large Subunit Ribosomal RNA Database. *Nucleic Acids Res* **29**: 175–177.
- Wuyts, J., Van de Peer, Y., Winkelmans, T. and De Wachter, R. (2002) The European database on small subunit ribosomal RNA. *Nucleic Acids Res* **30**: 183–185.
- Xu, D., and Cote, J.-C. (2003) Phylogenetic relationships between *Bacillus* species and related genera inferred from comparison of 3'-end 16S rDNA and 5'-end 16S-23S ITS nucleotide sequences. *Int J Syst Evol Microbiol* **53**: 695–704.
- Yap, W.H., Zhang, Z., and Wang, Y. (1999) Distinct types of rRNA operons exist in the genome of the actinomycete *Thermomonospora chromogena* and evidence for horizontal transfer of an entire rRNA operon. *J Bacteriol* **181**: 5201–5209.
- Yeager, C. M., Kornosky, J. L., Morgan, R. E., Cain, E. C., Garcia-Pichel, F., Housman, D. C., Belnap, J., and Kuske, C. R. (2007) Three distinct clades of cultured heterocystous cyanobacteria constitute the dominant N₂-fixing members of biological soil crusts of the Colorado Plateau, USA. *FEMS Microbiol Ecol* **60**: 85–97.
- Zehr, J. P., Limburger, R. J., Ohki, K., and Fujita, Y. (1990) Antiserum to nitrogenase generated from an amplified DNA fragment from natural populations of *Trichodesmium* spp. *Appl Environ Microbiol* **56**: 3527–3531.
- Zehr, J. P., Mellon, M. T., and Hiorns, W. D. (1997) Phylogeny of cyanobacterial *nifH* genes: evolutionary implications and potential applications to natural assemblages. *Microbiology (Reading)* **143**: 1443–1450.
- Zeigler, D. R. (2003) Gene sequences useful for predicting relatedness of whole genomes in bacteria. *Int J Syst Evol Microbiol* **53**: 1893–1900. doi: 10.1099/ijs.0.02713-0
- Zhaxybayeva, O., Lapierre, P., and Gogarten, J. P. (2004) Genome mosaicism and organismal lineages. *Trends Genet* **20**: 254–260.
- Zhaxybayeva, O., Gogarten, J. P., Charlebois, R. L., Doolittle, W. F., and Papke, R. T. (2006) Phylogenetic analyses of cyanobacterial genomes: quantification of horizontal transfer events. *Genome Res* **16**: 1099–1108. doi:10.1101/gt.5322306
- Zhaxybayeva, O., Doolittle, W. F., Papke, R. T., and Gogarten, J. P. (2009) Intertwined evolutionary histories of marine *Synechococcus* and *Prochlorococcus marinus*. *Genome Biol Evol* **1**: 325–339. doi: 10.1093/gbe/evp032
- Zuckerkandl, E., and Pauling, L. (1965) Evolutionary divergence and convergence in proteins. In: Bryson, V., and Vogel, H. J. (Eds.) *Evolving Genes and Proteins*. Academic Press, New York, NY, USA. pp. 97–166.

Taxonomy, Phylogeny and Evolution

- Abe, T. , Kanaya, S. , Kinouchi, M. , Ichiba, Y. , Kozuki, T. , and Ikemura, T. (2003) Informatics for unveiling hidden genome signatures. *Genome Res* 13: 693–702.
- Abed, R. M. M. , and Garcia-Pichel, F. (2001) Long-term compositional changes after transplant in a microbial mat cyanobacterial community revealed using a polyphasic approach. *Environ Microbiol* 3: 53–62.
- Abed, R. M. M. , Garcia-Pichel, F. , and Hernández-Mariné, M. (2002a) Polyphasic characterization of benthic, moderately halophilic, moderately thermophilic cyanobacteria with very thin trichomes and the proposal of *Halomicronema excentricum* gen. nov., sp. nov. *Arch Microbiol* 177: 361–370.
- Abed, R. M. M. , Safi, N. M. D. , Köster, J. , De Beer, D. , El-Nahal, Y. , Rullkötter, J. , and Garcia-Pichel, F. (2002b) Microbial diversity of a heavily polluted microbial mat and its community changes following degradation of petroleum compounds. *Appl Environ Microbiol* 68: 1674–1683.
- Acinas, S. G. , Haverkamp, T. H. A. , Huisman, J. , and Stal, L. J. (2009) Phenotypic and genotypic diversification of *Pseudoanabaena* spp. (Cyanobacteria). *Isme J* 3: 31–46.
- Al-Thukair, A. A. , Abed, R. M. M. , and Mohamed, L. (2007) Microbial community of cyanobacteria mats in the intertidal zone of oil-polluted coast of Saudi Arabia. *Mar Pollut Bull* 54: 173–179.
- Amann, R. I. , Binder, B. J. , Olson, R. J. , Chisholm, S. W. , Devereux, R. , and Stahl, D. A. (1990) Combination of 16S rRNA-targeted oligonucleotide probes with flow cytometry for analyzing mixed microbial populations. *Appl Environ Microbiol* 56: 1919–1925.
- Amann, R. I. , Ludwig, W. , and Schleifer, K.-H. (1995) Phylogenetic identification and in situ detection and identification of individual microbial cells with out cultivation. *Microbiol Rev* 59: 143–169.
- Amard, B. , and Bertrand-Sarfati, J. (1997) Microfossils in 2000 Ma old cherty stromatolites of the Franceville Group, Gabon. *Precambrian Res* 81: 197–221.
- Amikam, D. , Glaser, G. , and Razin, S. (1984) Mycoplasmas (Mollicutes) have a low number of rRNA genes. *J Bacteriol* 158: 376–378.
- Anagnostidis, K. , and Komárek, J. (1985) Modern approach to the classification system of the Cyanophytes 1: Introduction. *Arch Hydrobiol* 71: 291–302.
- Anagnostidis, K. , and Komárek, J. (1988) Modern approach to the classification system of cyanophytes. 3. Oscillatoriales. *Arch Hydrobiol suppl* 80: 327–472.
- Antón, A. I. , Martínez-murcia, A. J. , and Rodríguezvalera, F. (1998) Sequence diversity in the 16S-23S intergenic spacer region (ISR) of the rRNA operons in representatives of the *Escherichia coli* ECOR collection. *J Mol Evol* 47: 62–72.
- Barker, G.L. , Hayes, P.K. , O'Mahony, S.L. , Vacharapiyasophon, P. and Walsby, A. E. (1999) A molecular and phenotypic analysis of *Nodularia* (cyanobacteria) from the Baltic Sea. *J Phycol* 35: 931–937.
- Barker, G. L. , Handley, B. A. , Vacharapiyasophon, P. , Stevens, J. R. , and Hayes, P. K. (2000) Allele-specific PCR shows that genetic exchange occurs among genetically diverse *Nodularia* (cyanobacteria) filaments in the Baltic Sea. *Microbiology* 146: 2865–2875.
- Beiko, R. G. , and Charlebois, R. L. (2007) A simulation test bed for hypotheses of genome evolution. *Bioinformatics* 23: 825–831.
- Beiko, R. G. , Harlow, T. J. , and Ragan, M. A. (2005) Highways of gene sharing in prokaryotes. *Proc Natl Acad Sci USA* 102: 14332–14337.
- Beltran, E. C. , and Neilan, B. A. (2000). Geographical segregation of the neurotoxin-producing cyanobacterium *Anabaena circinalis*. *Appl Environ Microbiol* 66: 4468–4474.
- Ben-Porath, J. , Carpenter, E. J. , and Zehr, J. P. (1993) Genotypic relationships on *Trichodesmium* (Cyanophyceae) based on *nifH* sequence comparisons. *J Phycol* 29: 806–810.
- Bensaadi-Merchermek, N. , Salvado, J.-C. , Cagnon, C. , Karama, S. , and Mouchés, C. (1995). Characterization of the unlinked 16S rDNA and 23S-5S rRNA operon of *Wolbachia pipientis*, a prokaryotic parasite of insect gonads. *Gene* 165: 81–86.
- Benson, D.A. , Karsch-Mizrachi, I. , Lipman, D. J. , Ostell, J. , Rapp, B. A. , and Wheeler, D. L. (2002) GenBank. *Nucleic Acids Res* 30: 17–20.
- Bent, B. J. , Pierson, J. D. , and Forney, L. J. (2007) Measuring richness based on microbial community fingerprints: the Emperor has no clothes. *Appl Environ Microbiol* 73: 2399–2401.
- Bercovier, H. , Kafri, O. , and Sela, S. (1986) Mycobacteria possess a surprisingly small number of ribosomal RNA genes in relation to the size of their genome. *Biochem Biophys Res Commun* 136: 1136–1141.
- Berrendero, E. , Perona, E. , and Mateo, P. (2008) Genetic and morphological characterization of *Rivularia* and *Calothrix* (Nostocales, Cyanobacteria) from running water. *Int J Syst Evol Microbiol* 58: 447–460.
- Binder, B. J. , and Liu, Y. C. (1998) Growth rate regulation of rRNA content of a marine *Synechococcus* (cyanobacterium) strain. *Appl Environ Microbiol* 64: 3346–3351.
- Bittencourt-Oliveira, M. do. C. , Moura, A. do. N. , Oliveira, M. C. , and Massola Jr., N. S. (2009) *Geitlerinema* species (Oscillatoriales, Cyanobacteria) revealed cellular morphology, ultrastructure and DNA sequencing. *J Phycol* 45: 716–725.
- Blackwood, C. B. , and Buyer, J. S. (2007) Evaluating the physical capture method of terminal restriction fragment length polymorphism for comparison of soil microbial communities. *Soil Biol Biochem* 39: 590–599.
- Blackwood, C. B. , Marsh, T. , Kim, S.-H. , and Paul, E. A. (2003) Terminal restriction fragment length polymorphism data analysis for quantitative comparison of microbial communities. *Appl Environ Microbiol* 69: 926–932.
- Blackwood, C. B. , Hudleston, D. , Zak, D. R. , and Buyer, J. S. (2007) Interpreting ecological diversity indices applied to terminal restriction length polymorphism data: Insights simulated microbial communities. *Appl Environ Microbiol* 73: 5276–5283.
- Bolch, C. J. S. , Orr, P. , Jones, G. J. , and Blackburn, S. J. (1999) Genetic, morphological and toxicological variation among globally distributed strains of *Nodularia* (Cyanobacteria). *J Phycol* 35: 339–355.
- Boone, D. R. , and Castenholz, R. W. (Eds.) (2001). *Bergey's Manual of Systematic Bacteriology*, 2nd edn., Vol. 1. Springer-Verlag, New York, NY, USA.
- Bornet, E. , and Flahault, C. (1888) Revision des Nostocacées. *Ann Sci Nat Bot* 3: 323–381. 4: 343–373. 5: 51–129. 7: 177–262.
- Boucher, Y. , Douady, C. J. , Sharma, A. K. , Kamekura, M. , and Doolittle, W. F. (2004) Intragenomic heterogeneity and intergenomic recombination among haloarchaeal rRNA genes. *J Bacteriol* 186: 3980–3990.
- Bouchet, V. , Huot, H. , and Goldstein, R. (2008) Molecular genetic basis of ribotyping. *Clinical Microbiol Rev* 21: 262–273.
- Bourelly, P. (1970) Les algues d'eau douce III. N Boubéé et cie, Paris, pp.512.

Boutte, C. , Grubisic, S. , Balthasart, P. , and Wilmotte, A. (2006) Testing of primers for the study of cyanobacterial molecular diversity by DGGE. *J Microbiol Methods* 65: 542–550.

Boyer, S. L. , Flechtner, V. R. , and Johansen, J. R. (2001) Is the 16S-23S rRNA Internal transcribed spacer region a good tool for use in molecular systematics and population genetics? A case study in cyanobacteria. *Mol Biol Evol* 18: 1057–1069.

Brochier, C. , Philippe, H. and Moreira, D. (2000) The evolutionary history of ribosomal protein RpS14: horizontal gene transfer at the heart of the ribosome. *Trends Genet* 16: 529–533.

Brown, M. V. , Schwalbach, M. S. , Hewson, I. , and Fuhrman, J. A. (2005) Coupling 16S-ITS rDNA clone libraries and automated ribosomal intergenic spacer analysis to show marine microbial diversity: development and application to a time series. *Environ Microbiol* 7: 1466–1479.

Buchanan, R. E. , and Gibbons, N. E. (Eds.) (1974) *Bergey's Manual of Determinative Bacteriology*. Williams and Wilkins Co., Baltimore, MD, USA.

Callejas, C. , Gill, P. R. , Catalán, A. I. , Aziz, G. , Castro-Sowinski, S. and Batista, S. (2010) Phylotype diversity in a benthic cyanobacterial mat community on King George Island, maritime Antarctica *World J Microbiol Biotechnol* doi: 10.1007/s11274-010-0578-1

Carpenter, E. J. (1983) Nitrogen fixation by marine Oscillatoria (Trichodesmium) in the world's oceans. In: Carpenter, E. J. , and Capone, D.G. (Eds.) *Nitrogen in the Marine Environment*. Academic Press, New York, NY, USA. pp. 65–103.

Castenholz, R. W. (1992) Species usage, concept, and evolution in the cyanobacteria (blue-green algae). *J Phycol* 28: 737–745.

Castenholz, R. W. (2001) Phylum BX. Cyanobacteria. In: Boone, D. R. , and Castenholz, R. W. (Eds.) *Bergey's Manual of Systematic Bacteriology*, 2nd edn., Vol. 1.: Springer-Verlag, New York, NY, USA. pp. 473–487.

Castenholz, R. W. , and Norris, T. B. (2005) Revisionary concepts of species in the cyanobacteria and their applications. *Arch Hydrobiol Algol Stud* 117: 53–69.

Castenholz, R. W. , and Waterbury, J. B. (1989) Group I. Cyanobacteria. In: Krieg, N. R. , and Holt, J. G. (Eds.) *Bergey's Manual of Systematic Bacteriology*, vol. 3: Williams & Wilkins, Baltimore, MD, USA. pp. 1710–1728.

Castiglioni, B. , Rizzi, E. , Frosini, A. , Sivonen, K. , Rajaniemi, P. , Rantala, A. , Mugnai, M.A. , Ventura, S. , Wilmotte, A. , Boutte, C. , Grubisic, S. , Balthasart, P. , Consolandi, O. , Bordoni, R. , Mezzelani, A. , Battaglia, C. , and De Bellis, G. (2004) Development of a universal microarray based on the ligation detection reaction and 16SrRNA gene polymorphism to target diversity of cyanobacteria. *Appl Environ Microbiol* 70: 7161–7172.

Cavalier-Smith, T. (2001) Obcells as proto-organisms: membrane heredity, lithophosphorylation, and the origins of the genetic code, the first cells, and photosynthesis. *J Mol Evol* 53: 555–595.

Cavalier-Smith, T. (2002) The neomuran origin of archaeobacteria, the negibacterial root of the universal tree and bacterial megaclassification. *Int J Syst and Evol Microbiol* 52: 7–76.

Chen, F. , Wang, K. , Kan, J. , Suzuki, M. T. , and Wommack, K. E. (2006) Diverse and unique picocyanobacteria in Chesapeake Bay, revealed by 16S-23S rRNA internal transcribed spacer sequences. *Appl Environ Microbiol* 72: 2239–2243.

Chen, X. , and Widger, W. R. (1993) Physical genome map of the unicellular cyanobacterium *Synechococcus* sp. strain PCC 7002.. *J Bacteriol* 175: 5106–5116.

Chenna, R. , Sugawara, H. , Koike, T. , Lopez, R. , Gibson, T. J. , Higgins, D. G. , and Thompson, J. D. (2003) Multiple sequence alignment with the Clustal series of programs. *Nucleic Acids Res* 31: 3497–3500.

Chisholm, S. W. (1992) Phytoplankton size. In: Falkowski, P. G. and Woodhead, A. D. (Eds.) *Primary Productivity and Biogeochemical Cycles in the Sea*. Plenum Press, New York, NY, USA. pp. 213–237.

Chisholm, S. W. , Frankel, S. L. , Goericke, R. , Olson, R. J. , Palenik, B. , Waterbury, J. B. , West-Johnsrud, L. , and Zettler, E. R. (1992) *Prochlorococcus marinus* nov. gen. nov. sp.: an oxyphototrophic marine prokaryote containing divinyl chlorophyll a and b. *Arch Microbiol* 157: 297–300.

Chisholm, S. W. , Olson, R. J. , Zettler, E. R. , Goericke, R. , Waterbury, J. , and Welschmeyer, N. (1988) A novel free-living prochlorophyte abundant in the oceanic euphotic zone. *Nature (London)* 334: 340–343.

Clemente, J. C. , Satou, K. , and Valiente, G. (2006) Phylogenetic reconstruction from non-genomic data. *Bioinformatics* 23: e110–e115. doi: 10/bioinformatics/bt1307

Cohan, F. M. (2002) What are bacterial species? *Annu Rev Microbiol* 56: 457–487. doi: 10.1146/annurev.micro.56.012302.160634

Cohan, F. M. (2006) Towards a conceptual and operational union of bacterial systematic, ecology and evolution. *Phil Trans R Soc B* 361: 1985–1996.

Cohn, F. (1872) Grundzüge einer neuen natürlichen Anordnung der Kryptogamischen Pflanzen. *Jahrb Schles Ges Vaterl KuH* 49: 83–89.

Cohn, F. (1875) Untersuchungen über Bakterien. II. *Beitr Biol Pflanz* 1: 141–207.

Cottret, L. , Wildridge, D. , Vinson, F. , Barrett, M. P. , Charles, H. , Sagot, M. F. , and Jourdan, F. (2010) Met Explore: a webserver to link metabolic experiments and genome-scale metabolic net works. *Nucleic Acids Res* 38: W132–W137. doi: 10.1093/nar/gicq312

Crosbie, N. D. , Pöckl, M. , and Weisse, T. (2003) Dispersal and phylogenetic diversity of nonmarine picocyanobacteria, inferred from 16S rRNA gene and cpc-intergenic spacer sequence analysis. *Appl Environ Microbiol* 69: 5716–5721.

D'Auria, G. , Pushker, R. , and Rodríguez-Valera, F. (2006) IWoCS: analyzing ribosomal intergenic transcribed spacers configuration and taxonomic relationships. *Bioinformatics* 22: 527–531.

Dagan, T. , Artzy-Randrup, Y. , and Martin, W. (2008) Modular networks and cumulative impact of lateral transfer in prokaryote genome evolution. *Proc Natl Acad Sci USA* 105: 10039–10044.

Danovaro, R. , Luna, G. M. , Dell'Anno, A. , and Pietrangeli, B. (2006) Comparison of two fingerprinting techniques, terminal restriction fragment length polymorphism and automated ribosomal intergenic spacer analysis, for determination of bacterial diversity in aquatic environments. *Appl Environ Microbiol* 72: 5982–5989.

Darwin, C. (1859) *On the Origin of Species*. Murray, London.

Darwin, C. (1872) *The Origin of Species*. 6th edn. Murray, London.

Desikachary, T. V. (1959) *Cyanophyta*. Indian Council Agricultural Research, New Delhi.

De Vos, P. , and Trüper, H. G. (2000) Judicial Commission of the International Committee on Systematic Bacteriology. IXth International (IUMS) Congress of Bacteriology and Applied Microbiology. Minutes of the meetings, 14, 15 and 18 August 1999, Sydney, Australia. *Int J Syst Evol Microbiol* 50: 2239–2244.

Dobzhansky, T. (1937) *Genetics and the Origin of Species*. Columbia University Press, New York, NY, USA.

Dobzhansky, T. (1951) *Genetics and the Origin of Species*. 2nd edn. Columbia University Press, New York, NY, USA.

- Doolittle, R. F. , Feng, D. F. , Tsang, S. , Cho, G. , and Little, E. (1996) Determining divergence times of the major kingdoms of living organisms with a protein clock. *Science* 271: 470–477.
- Doolittle, W. F. , and Bapteste, E. (2007) Pattern pluralism and the tree of life hypothesis. *Proc Natl Acad Sci USA* 104: 2043–2049.
- Drouet, F. (1981) Revision of the Stigonemataceae with a summary of the classification of the blue-green algae. *Nova Hedwigia* 66: 1–221.
- Drouet, F. , and Daily, W. A. (1956) Revision of the coccoid Myxophyceae. *Butler University Botanical Studies* 12: 1–218.
- Dunbar, J. , Ticknor, L. O. , and Kuske, C. R. (2000) Assessment of microbial diversity in four southwestern United States soils by 16S rRNA gene terminal restriction fragment analysis. *Appl Environ Microbiol* 66: 2943–2950.
- Dunbar, J. , Ticknor, L. O. , and Kuske, C. R. (2001) Phylogenetic specificity and reproducibility and new method for analysis of terminal restriction fragment profiles of 16S rRNA genes from bacterial communities. *Appl Environ Microbiol* 67: 190–197.
- Egholm, M. , Buchardt, O. , Christensen, L. , Behrens, C. , Freler, S. M. , Driver, D. A. , Berg, R. H. , Kim, S. K. , Norden, B. , and Nielsen, P. E. (1993) PNA hybridizes to complementary oligonucleotides obeying the Watson-Crick hydrogen bonding rules. *Nature (London)* 365: 266–268.
- Eisen, J. A. (1998) Phylogenomics: Improving functional predictions for uncharacterized genes by evolutionary analysis. *Genome Res* 8: 163–167.
- Eisen, J. A. , and Fraser, C. M. (2003) Phylogenomics: Intersection of evolution and genomics. *Science* 300: 1706–1707.
- El Fantroussi, S. , Urakawa, H. , Bernhard, A. E. , Kelly, J. J. , Noble, P. A. , Smidt, H. , Yershov, G. M. and Stahl, D. A. (2003) Direct profiling of environmental microbial populations by thermal dissociation analysis of native rRNAs hybridized to oligonucleotide microarrays. *Appl Environ Microbiol* 69: 2377–2382.
- El Herry, S. , Nasri, H. , and Bouaïcha, N. (2008) Morphological and phylogenetic analysis of colonies of *Microcystis* morphospecies isolated from the Lebna Dam, Tunisia. *Afr J Microbiol Res* 2: 340–348.
- Engbretonson, J. J. , and Moyer, C. L. (2003) Fidelity of select restriction endonucleases in determining microbial diversity by terminal-restriction fragment length polymorphism. *Appl Environ Microbiol* 69: 4823–4829.
- Ernst, A. , Marschall, P. , and Postius, C. (1995) Genetic diversity among *Synechococcus* spp. (cyanobacteria) isolated from the pelagial of Lake Constance. *FEMS Microbiol Ecol* 17: 197–204.
- Ernst, A. , Becker, S. , Wollenzien, U. I. A. , and Postius, C. (2003) Ecosystem dependent adaptive radiations of picocyanobacteria inferred from 16S rRNA and ITS-1 sequence analysis. *Microbiology* 149: 217–228.
- Fantroussi, S. E. , Urakawa, H. , Bernhard, A. E. , Kelly, J. J. , Noble, P. A. , Smidt, H. , Yershov, G. M. , and Stahl, D. A. (2003) Direct profiling of environmental microbial populations by thermal dissociation analysis of native rRNAs hybridized to oligonucleotide microarrays. *Appl Environ Microbiol* 69: 2377–2382.
- Felsenstein, J. (1989) PHYLIP-Phylogeny Inference Package (version 3.2). *Cladistics* 5: 164–166.
- Fergusson, K. M. , and Saint, C. P. (2000) Molecular phylogeny of *Anabaena circinalis* and its identification in environmental samples by PCR. *Appl Environ Microbiol* 66: 4145–4148.
- Ferris, M. J. , and Ward, D. M. (1997) Seasonal distributions of dominant 16S rRNA defined populations in a hot spring microbial mat examined by denaturing gradient gel electrophoresis. *Appl Environ Microbiol* 63: 1375–1381.
- Ferris, M. J. , Kühl, M. , Wieland, A. , and Ward, D. M. (2003) Cyanobacterial ecotypes in different optical microenvironments of a 68° C hot spring mat community revealed by 16S-23S rRNA internal transcribed spacer region variation. *Appl Environ Microbiol* 69: 2893–2898.
- Fisher, R. A. (1930) *Genetical Theory of Natural Selection*. Oxford University Press, Oxford., England, UK.
- Floyd, M. M. , Tang, J. , Kane, M. , and Emerson, D. (2005) Captured diversity in a culture collection. Case study of the geographic and habitat distributions of environmental isolates held at the American Type Culture Collection. *Appl Environ Microbiol* 71: 2813–2823.
- Foerstner, K. U. , von Mering, C. , and Bork, P. (2006) Comparative analysis of environmental sequences: potential and challenges. *Phil Trans R Soc B* 361: 519–523.
- Fraser, C. , Alm, E. J. , Polz, M. F. , Spratt, B. G. , and Hanage, W. P. (2008) The bacterial species challenge: making sense of genetic and ecological diversity. *Science* 323: 741–746.
- Fritsch, F. E. (1945) *The Structure and Reproduction of Algae*, vol II. Cambridge University Press, Cambridge, England, UK.
- Fox, G. E. , Peckman, K. J. , and Woese, C. R. (1977) Comparative cataloging of 16S ribosomal ribonucleic acid: molecular approach to prokaryotic systematics. *Int J Syst Bacteriol* 27: 44–57.
- Fox, G. E. , Wisotzkey, J. D. , and Jurtshuk Jr., P. (1992) How close is close: 16S rRNA sequence identity may not be sufficient to guarantee species identity. *Int J Syst Bacteriol* 42: 166–170.
- Fukunaga, M. , and Mifuchi, I. (1989). Unique organization of *Leptospira interrogans* rRNA genes. *J Bacteriol* 171: 5763–5767.
- Fuller, N. J. , Marie, M. D. , Partensky, F. , Vaulot, D. , Post, A. F. , and Scanlan, D. J. (2003) Clade-specific 16S ribosomal DNA oligonucleotides reveal the predominance of a single marine *Synechococcus* clade throughout a stratified water column in the Red Sea. *Appl Environ Microbiol* 69: 2430–2443.
- Furukawa, K. , Noda, N. , Tsureda, S. , Saito, T. , Itayama, T. , and Inamori, Y. (2006) Highly sensitive real-time PCR assay for quantification of toxic cyanobacteria based on microcystin synthase A gene. *J Biosci and Bioeng* 102: 90–96.
- Gans, J. , Wolinsky, M. , and Dunbar, J. (2005) Computational improvements reveal great bacterial diversity and high metal toxicity in soil. *Science* 309: 1387–1390.
- García-Martínez, J. , Bescós, I. , Rodríguez-Sala, J. J. , and Rodríguez-Valera, F. (2001) RISSC: a novel database for ribosomal 16S-23S RNA genes spacer regions. *Nucleic Acids Res* 29: 178–180.
- Garcia-Pichel, F. (2000) Cyanobacteria. In: Lederberg, J. (Ed.) *Encyclopedia of Microbiology*. 2nd edn. Academic Press, San Diego, CA, USA. pp. 907–927.
- Garcia-Pichel, F. , Nübel, U. , and Muyzer, G. (1998) The phylogeny of unicellular, extremely halotolerant cyanobacteria. *Arch Microbiol* 169: 469–482.
- García-Vallvé, S. , Romeu, A. , and Palau, P. (2000) Horizontal gene transfer in bacterial and archaeal complete genomes. *Genome Res* 10: 1719–1725.
- Garnier, T. , Canard, B. , and Cole, S. T. (1991). Cloning, mapping, and molecular characterization of the rRNA operons of *Clostridium perfringens*. *J Bacteriol* 173: 5431–5438.
- Garrity, G. M. , and Holt, J. G. (2001) The road map to the manual. In: Boone, D. R. , and Castenholz, R. W. (Eds.) *Bergey's Manual of Systematic Bacteriology*. 2nd edn. Springer-Verlag, New York, NY, USA. pp. 119–155.

Geitler, L. (1932) Cyanophyceae. In: Kolkwitz, R. (Ed.) Rabenhorst's Kryptogamenflora von Deutschland, Österreich und der Schweiz, Vol 14. Akademische Verlagsgesellschaft, Leipzig, Germany. pp 1–1196.

Gest, H. (1999) Bacterial classification and taxonomy: "a primer" for the new millennium. *Microbiology Today* 26: 70–72.

Gevers, D. , Cohan, F. M. , Lawrence, J. G. , Spratt, B. G. , Coenye, T. , Feil, E. J. , Stackebrandt, E. , Van de Peer, Y. , Vandamme, P. , Thompson, F. L. , and Swings, J. (2005) Opinion: re-evaluating prokaryotic species. *Nat Rev Microbiol* 3: 733–739.

Gibbons, N. E. , and Murray, R. G. E. (1978) Validation of Cyanobacteriales Stanier in Gibbons and Murray 1978 as a new order of the kingdom Procaryotae Murray 1968, and of the use of neuter plural endings for Photobacteria and Scotobacteria classes nov. Gibbons and Murray 1978. Request for an opinion. *Int J Syst Bacteriol* 28: 332–333.

Giovannoni, S. J. , Turner, S. , Olsen, G. J. , Barns, S. , Lane, D. J. , and Pace, N. R. (1988) Evolutionary relationships among cyanobacteria and green chloroplasts. *J Bacteriol* 170: 3584–3592.

Goerick, R. , and Repeta, D. J. (1992) The pigments of *Prochlorococcus marinus*: the presence of divinyl-chlorophyll a and b in a marine prokaryote. *Limnol Oceanogr* 37: 425–433.

Gogarten, J. P. , and Townsend, J. P. (2005) Horizontal gene transfer, genome innovation and evolution. *Nat Rev Microbiol* 3: 679–687.

Gogarten, J. P. , Doolittle, W. F. and Lawrence, J.G. (2002) Prokaryotic evolution in light of gene transfer. *Mol Biol Evol* 19: 2226–2238.

Gogarten, J. P. , Olendzenski, L. , Hilario, E. , Simon, C. , and Holsinger, K. E. (1996) Dating the cenacester of organisms. *Science* 274: 1750–1751.

Golubic, S. (1967) Algenvegetation der Felsen, eine oekologische Algenstudie im dinarischen Karstgebiet (Algal Vegetation on Cliffs, an Ecological Study of Algae in the Dinaric karstic Region). "Binnengewasser" 23: 1–183. Schweizerbart'sche Verlagsbuchhandlung, Stuttgart, Germany.

Golubic, S. , and Hofmann, H. J. (1976) Comparison of Holocene and mid-Precambrian Entophysalidaceae (Cyanophyta) in stromatolitic algal mats: cell division and degradation. *J Paleontol* 50: 1074–1082.

Golubic, S. , Sergeev, V. N. , and Knoll, A. H. (1995) Mesoproterozoic Archaeoellipsoides: akinetes of heterocystous cyanobacteria. *Lethaia* 28: 285–298.

Gomont, M. (1892) Monographie des Oscillariées. *Ann Sci Nat Ser Bot* 15: 263–368. 16: 91–264.

Goncalves, E. R. , and Rosato, Y. B. (2002) Phylogenetic analysis of *Xanthomonas* species based upon 16S-23S rDNA intergenic spacer sequences. *Int J Syst Evol Microbiol* 52: 355–361.

Gotelli, N. J. , and Colwell, R. K. (2001) Quantifying biodiversity: procedures and pitfalls in the measurement and comparison of species richness. *Ecol Lett* 4: 379–391.

Gould, S. J. , and Eldredge, N. (1993) Punctuated equilibrium comes of age. *Nature (London)* 366: 223–227.

Grimont, F. , and Grimont, P. A. (1986) Ribosomal ribonucleic acid gene restriction patterns as potential taxonomic tools. *Ann Inst Pasteur Microbiol* 137B: 165–175.

Guasp, C. , Moore, E. R. B. , Lalucat, J. , and Bennasar, A. (2000) Utility of internally transcribed 16S-23S rDNA spacer regions for the definition of *Pseudomonas stutzeri* genomovars and other *Pseudomonas* species. *Int J Syst Evol Microbiol* 50: 1629–1639.

Gugger, M. F. , and Hoffmann, L. (2004) Polyphyly of the true branching cyanobacteria (Stigonematales). *Int J Syst Evol Microbiol* 54: 349–357.

Gugger, M. , Lyra, C. , Henriksen, P. , Couté, A. , Humbert, J.-F. , and Sivonen, K. (2002) Phylogenetic comparison of the cyanobacterial genera *Anabaena* and *Aphanizomenon*. *Int J Syst Evol Microbiol* 52: 1–14.

Gupta, R. S. (1998) Protein phylogenies and signature sequences: A reappraisal of evolutionary relationships among Archaeobacteria, Eubacteria and Eukaryotes. *Microbiol Mol Biol Rev* 62: 1435–2140.

Gürtler, V. , and Stanisich, V. (1996) New approaches to typing and identification of bacteria using the 16S-23S rDNA spacer region. *Microbiology* 142: 3–16.

Guschin, D. , Mobarry, B. , Proudnikov, D. , Stahl, D. , Rittmann, B. , and Mirzabekov, A. (1997) Oligonucleotide microchips as genosensors for determinative and environmental studies in microbiology. *Appl Environ Microbiol* 63: 2397–2402.

Hacker, J. , and Kaper, J.B. (2000) Pathogenicity islands and the evolution of microbes. *Annu Rev Microbiol* 54: 641–679.

Haldane, J. B. S. (1932) The Causes of Evolution. Princeton University Press, Princeton, N.J. USA.

Hanage, W. P. , Fraser, C. , and Spratt, B. G. (2006) Sequences, sequence clusters and bacterial species. *Phil Trans R Soc B* 361: 1917–1927. doi: 10.1098/rstb.2006.1917

Hao, W. , and Golding, G. B. (2004) Patterns of bacterial gene movement. *Mol Biol Evol* 21: 1294–1307.

Hayes, P. K. , and Barker, G. L. (1997) Genetic diversity within Baltic Sea populations of *Nodularia* (Cyanobacteria). *J Phycol* 33: 919–923.

Henson, B. J. , Hesselbrock, S. M. , Watson, L. E. , and Barnum, S. R. (2004) Molecular phylogeny of the heterocystous cyanobacteria (Subsections IV and V) based on *nifD*. *Int J Syst Evol Microbiol* 54: 493–497.

Herdman, M. , Janvier, J. B. , Waterbury, J. B. , Rippka, R. , Stanier, R. Y. , and Mandel, M. (1979). Deoxyribonucleic acid base composition of cyanobacteria. *J Gen Microbiol* 111: 63–71.

Hoffmann, L. , and Castenholz, R. W. (2001) Subsection V. (Formerly Stigonematales Geitler 1925). In: Boone, D. R. , and Castenholz, R. W. (Eds.) *Bergey's Manual of Systematic Bacteriology*, 2nd edn., vol. 1, Springer-Verlag, New York, NY, USA. pp. 589–599.

Hoffmann L. , Kaštovský J. , and Komárek, J. (2005) Proposal of cyanobacterial system, 2004. In: Komárek J. , and Anagnostidis K. (2005). *Cyanoprokaryota*, 2. Teil/2nd Part: Oscillatoriales. In: Büdel B., Krienitz L., Gärtner G., and Schagerl, M. (Eds.) *Süßwasserflora von Mitteleuropa* 19/2, Elsevier/Spektrum, Heidelberg, Germany. pp. 657–660.

Holben, W. E. , Feris, K. P. , Kettunen, A. , and Apajalahti, J. H. A. (2004) GC Fractionation enhances microbial community diversity assessment and detection of minority populations of bacteria by denaturing gradient gel electrophoresis. *Appl Environ Microbiol* 70: 2263–2270.

Holt, J. G. (1979). International Committee on Systematic Bacteriology. Judicial Commission. Minutes of the Meeting, 3 September 1978, Munich, West Germany. *Int J Syst Bacteriol* 29, 267–269.

Holt, J. G. , Krieg, N. R. , Sneath, P. H. A. , Staley, J. T. , and Williams, S. T. (1994) Group 11. Oxygenic phototrophic bacteria. In: Holt, J. G. (Ed.) *Bergey's Manual of Determinative Bacteriology*, 9th edn., Williams & Wilkins, Baltimore, MD, USA. pp. 377–425.

Honda, D. , Yokota, A. , and Sugiyama, J. (1999) Detection of seven major evolutionary lineages in cyanobacteria based on the 16S rRNA gene sequence analysis with new sequences of five marine *Synechococcus* strains. *J Mol Evol* 48: 723–739.

Horz, H. , Yimga, M. T. , and Liesack, W. (2001) Detection of methanotroph diversity on roots of submerged rice plants by molecular retrieval of *pmoA*, *mmoX*, *mxsA*, and 16S rRNA and ribosomal DNA, including *pmoA*-based terminal restriction fragment length polymorphism profiling. *Appl Environ Microbiol* 67: 4177–4185.

- Hull, D. L. (1997) Species: the units of biodiversity. The ideal species concept—and why we can't get it. Chapman and Hall, London, UK.
- Hulton, C. S. J. , Higgins, C. F. , and Sharp, M. P. (1991). ERIC sequences: a novel family of repetitive elements in the genomes of *Escherichia coli*, *Salmonella typhimurium* and other enterobacteria. *Mol Microbiol* 5: 825–834.
- Huys, G. , Coopman, R. , Janssen, P. , and Kersters, K. (1996) High resolution genotypic analysis of the genus *Aeromonas* by AFLP fingerprinting. *Intl J Syst Bacteriol* 46: 572–580.
- Ishida, T. , Yokota, A. , and Sugiyama, J. (1997) Phylogenetic relationships of filamentous cyanobacterial taxa inferred from 16S rRNA sequence divergence. *J Gen Appl Microbiol* 43: 237–241.
- Iteman, I. , Rippka, R. , Tandeau de Marsac, N. , and Herdman, M. (2000) Comparison of conserved structural and regulatory domains within divergent 16S rRNA-23S rRNA spacer sequences of cyanobacteria. *Microbiology* 146: 1275–1286.
- Iteman, I. , Rippka, R. , Tandeau de Marsac, N. , and Herdman, M. (2002) rDNA analyses of planktonic heterocystous cyanobacteria including members of the genera *Anabaenopsis* and *Cyanospira*. *Microbiology* 148: 481–496.
- Iyer, L.M. , Koonin, E.V. and Aravind, L. (2004) Evolution of bacterial RNA polymerase: implications for large-scale bacterial phylogeny, domain accretion, and horizontal gene transfer. *Gene* 335: 73–88.
- Jain, R. , Rivera, M.C. , and Lake, J.A. (1999) Horizontal gene transfer among genomes: The complexity hypothesis. *Proc Natl Acad Sci USA* 96: 3801–3806.
- Janse, I. , Meima, M. , Kardinaal, W. E. A. , and Zwart, G. (2003) High-resolution differentiation of cyanobacteria by using rRNA-internal transcribed spacer denaturing gradient gel electrophoresis. *Appl Environ Microbiol* 69: 6634–6643.
- Janson, S. , Bergman, B. , Carpenter, E. J. , Giovannoni, S. , and Vergin, K. 1999 Genetic analysis of natural populations of the marine diazotrophic cyanobacterium *Trichodesmium*. *FEMS Microbiol Ecol* 30: 57–65.
- Janson, S. , Siddiqui, P. J. A. , Walsby, A. E. , Romans, K. M. , Carpenter, E. J. , and Bergman, B. (1995) Cytomorphological characterization of the planktonic diazotrophic cyanobacteria *Trichodesmium* spp. from the Indian Ocean and Caribbean and Sargasso Seas. *J Phycol* 31: 463–477.
- Janssen, P. , Coopman, R. , Huys, G. , Swings, J. , Bleeker, H. , Vos, P. , Zabeau, M. , and Kersters, K. (1996) Evaluation of the DNA fingerprinting methods: AFLP as a new tool in bacterial taxonomy. *Microbiology* 142: 1881–1893.
- Jaspers, E. , and Overmann, K. (2004) Ecological significance of microdiversity: identical 16S rRNA gene sequences can be found in bacteria with highly divergent genomes and ecophysiologicals. *Appl Environ Microbiol* 70: 4831–4839.
- Jungblut, A-D. , Hawes, I. , Mountfort, D. , Hitzfeld, B. , Dietrich, D. R. , Burns, B. P. , and Neilan, B. A. (2005) Diversity with in cyanobacterial mat communities in variable salinity meltwater ponds of McMurdo Ice Shelf, Antarctica. *Environ Microbiol* 7: 519–529. doi: 10.1111/j.1462-2920.2005.00717.x
- Kaneko, T. , Sato, S. , Kotani, H. , Tanaka, A. , Asamizu, E. , Nakamura, Y. , Miyajima, N. , Hirose, M. , Sugiyama, M. , Sasamoto, S. , Kimura, T. , Hosouchi, T. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Naruo, K. , Okumura, S. , Shimpo, S. , Takeuchi, C. , Wada, T. , Watanabe, A. , Yamada, M. , Yasuda, M. and Tabata, S. (1996) Sequence analysis of the genome of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. II. Sequence determination of the entire genome and assignment of potential protein-coding regions.. *DNA Res* 3: 109–136.
- Kardinaal, W. E. A. , Janse, I. , Kamst-van Agterveld, M. , Meima, M. , Snoek, J. , Mur, L. R. , Huisman, J. , Zwart, G. , and Visser, P. M. (2007) *Microcystis* genotype succession in relation to microcystin concentrations in freshwater lakes. *Aquat Microb Ecol* 48: 1–12.
- Karlin, S. , and Burge, C. (1995) Dinucleotide relative abundance extremes: a genomic signature. *Trends Genet* 11: 283–290.
- Keswani, J. , and Whitman, W. B. (2001) Relationship of 16S rRNA sequence similarity to DNA hybridization in prokaryotes. *Int J Syst Evol Microbiol* 51: 667–678.
- Kim, S-G. , Rhee, S-K. , Ahn, C. Y. , Ko, S-R. , Choi, G-G. , Bae, J-W. , Park, Y-H. , and Oh, H-M. (2006) Determination of cyanobacterial diversity during algal blooms in Daechung reservoir, Korea, on the basis of *cpcBA* intergenic spacer analysis. *Appl Environ Microbiol* 72: 3252–3258.
- Kimura, M. (1980) A simple method for estimating evolutionary rates of base substitutions through comparative studies of nucleotide sequences. *J Mol Evol* 16: 111–120.
- Kimura, M. (1983) The neutral theory of molecular evolution. In: M. Nei and R. K. Koehn (Eds.), *Evolution of Genes and Proteins*. Sinauer Associates Inc. Publishers, Sunderland, MA, USA. pp. 208–233.
- King, J. L. , and Jukes, T. H. (1969) Non-Darwinian evolution. *Science* 164: 788–798.
- Kitts, C. L. (2001) Terminal-restriction fragment patterns: a tool for comparing microbial communities and assessing community dynamics. *Curr Issues Intest Microbiol* 2: 17–25.
- Koizumi, Y. , Kelly, J. J. , Nakagawa, T. , Urakawa, H. , El-Fantroussi, S. , Al-Muzaini, S. , Fukui, M. , Urushigawa, Y. and Stahl, D.A. (2002) Parallel characterization of anaerobic toluene- and ethylbenzene-degrading microbial consortia by PCR-denaturing gradient gel electrophoresis, RNA-DNA membrane hybridization, and DNA microarray technology. *Appl Environ Microbiol* 68: 3215–3225.
- Komárek, J. (2003) Problem of the taxonomic category “species” in cyanobacteria. *Arch Hydrobiol Algol Stud* 109: 281–297.
- Komárek, J. (2005) The modern classification of Cyanoprokaryotes (cyanobacteria). *Oceanological and Hydrobiological Studies Vol XXXIV*, Supplement 3, pp. 5–17.
- Komárek, J. , and Anagnostidis, K. (1986) Modern approach to the classification system of Cyanophytes. 2: Chroococcales. *Arch Hydrobiol Algol Stud* 43: 157–226.
- Komárek, J. , and Anagnostidis, K. (1989). Modern approach to the classification system of Cyanophytes 4. Nostocales. *Arch Hydrobiol Suppl* 82: 247–334.
- Komárek, J. , and Kovacik, L. (1989) Trichome structure of four Aphanizomenon taxa (Cyanophyceae) from Czechoslovakia, with notes on the taxonomy and delimitation of the genus. *Plant Syst Evol* 164: 47–64.
- Komárek, J. , and Komárkova, J. (2006) Diversity of Aphanizomenon-like cyanobacteria. *Czech Phycology, Olomouc* 6: 1–32.
- Konstantinidis, K. T. , and Tiedje, J. M. (2005) Genomic insights that advance the species definition for prokaryotes. *Proc Natl Acad Sci USA* 102: 2567–2572. doi: 10.1073/pnas.0409727102
- Konstantinidis, K. T. , Ramette, A. , and Tiedje, J. M. (2006) The bacterial species definition in the genomic era. *Phil Trans R Soc B* 361: 1929–1940. doi: 10.1098/rstb.2006.1920.
- Konstantinidis, K. T. , and Tiedje, J. M. (2007) Prokaryotic taxonomy and phylogeny in the genomic era: advancements and challenges ahead. *Curr Opin Microbiol* 10: 504–509.
- Koonin, E. V. (2009) Darwinian evolution in the light of genomics. *Nucleic Acids Res* 37: 1011–1034.

Kumari, N. , Srivastava, A. K. , Bhargava, P. , and Rai, L. C. (2009) Molecular approaches towards assessment of cyanobacterial diversity. *Afr J Biotechnol* 8: 4284–4298. <http://academicjournals.org/AJB>

Kurmayer, R. , Dittmann, E. , Fastner, J. , and Chorus, I. E. (2002) Diversity of microcystin genes within a population of the toxic cyanobacterium *Microcystis* spp. in Lake Wannsee (Berlin, Germany). *Microb Ecol* 43: 107–118.

Kwon, S. W. , Park, J.-Y. , Kim, J.-S. , Kang, J.-W. , Cho, Y.-H. , Lim, C.-K. , Parker, M. A. , and Lee, G.-B. (2005) Phylogenetic analysis of the genera *Bradyrhizobium*, *Mesorhizobium*, *Rhizobium*, and *Sinorhizobium* on the basis of 16S rRNA gene and internally transcribed spacer region sequences. *Int J Syst Evol Microbiol* 55: 263–270.

Laamanen, M. J. , Forsström, L. , and Sivonen, K. (2002) Diversity of *Aphanizomenon flos-aquae* (cyanobacterium) populations along a Baltic Sea salinity gradient. *Appl Environ Microbiol* 68: 5296–5303.

Lachance, M. (1981) Genetic relatedness of heterocystous cyanobacteria by deoxyribonucleic acid-deoxyribonucleic acid reassociation. *Int J Syst Evol Microbiol* 31: 139–147.

Laguerre, G. , Allard, M. , Revoy, F. , and Amarger, N. (1994) Rapid identification of rhizobia by restriction fragment length polymorphism analysis of PCR-amplified 16S rRNA genes. *Appl Environ Microbiol* 60: 56–63.

Laloui, W. , Palinska, K.A. , Rippka, R. , Partensky, F. , Tandeau de Marsac, N. , Herdman, M. , and Iteman, I. (2002) Genotyping of axenic and non-axenic isolates of the genus *Prochlorococcus* and the OMF-*'Synechococcus'* clade by size, sequence analysis or RFLP of the internal transcribed spacer of the ribosomal operon. *Microbiology* 148: 453–465.

Lane, D.J. , Pace, B. , Olsen, G. J. , Stahl, D. A. , Sogin, M. L. and Pace, N. R. (1985) Rapid determination of 16S ribosomal RNA sequences for phylogenetic analyses. *Proc Natl Acad Sci USA* 82: 6955–6959.

Larkin, M. A. , Blackshields, G. , Brown, N. P. , Chenna, R. , McGettigan, P. A. , McWilliam, H. , Valentin, F. , Wallace, I. M. , Wilm, A. , Lopez, R. , Thompson, J. D. , Gibson, T. J. and Higgins, D. G. (2007) ClustalW and ClustalX version 2.0. *Bioinformatics* 23: 2947–2948. doi: 10.1093/bioinformatics/blm004

Lavin, P. , Gómez, P. , González, B. , and Ulloa, O. (2008) Diversity of the marine picocyanobacteria *Prochlorococcus* and *Synechococcus* assessed by terminal restriction fragment length polymorphisms of 16S-23S rRNA internal transcribed spacer sequences. *Revista Chilena de Historia Natural* 81: 515–531.

Lawrence, J. G. , and Ochman, H. C. (1998) Molecular archaeology of *Escherichia coli* genome. *Proc Natl Acad Sci USA* 95: 9413–9417.

Lebaron, P. , Catala, P. , Fajon, C. , Joux, F. , Baudart, J. , and Bernard, L. (1997) A new sensitive, whole cell hybridization technique for detection of bacteria involving a biotinylated oligonucleotide probe targeting rRNA and tyramide signal amplification. *Appl Environ Microbiol* 63: 3274–3278.

Lehtimäki, J. , Lyra, C. , Suomalainen, S. , Sundman, P. , Rouhiainen, L. , Paulin, L. , Salkinoja-Salonen, M. , and Sivonen, K. (2000) Characterization of *Nodularia* strains, cyanobacteria from brackish waters, by genotypic and phenotypic methods. *Int J Syst Evol Microbiol* 50: 1043–1053.

Li, R. , Carmichael, W. W. , Liu, Y. , and Watanabe, M. M. (2000) Taxonomic revaluation of *Aphanizomenon flos-aquae* NH-5 based on morphology and 16S rRNA gene sequences. *Hydrobiologia* 438: 99–105.

Ligon, P. J. B. , Meyer, K. G. , Martin, J. A. , and Curtis, S. E. (1991) Nucleotide sequence of a 16S rRNA gene from *Anabaena* sp. strain PCC 7120. *Nucleic Acids Res* 19: 4553.

Liu, W.-T. , Marsh, T. L. , Cheng, H. , and Forney, L. J. (1997) Characterization of microbial diversity by determining terminal restriction fragment length polymorphism of genes encoding 16S rRNA. *Appl Environ Microbiol* 63: 4516–4522.

Liu, W.-T. , Mirzabekov, A. D. , and Stahl, D. A. (2001) Optimization of an oligonucleotide microchip for microbial identification studies: a non-equilibrium dissociation approach. *Environ Microbiol* 3: 619–629.

Liu, Z. , DeSantis, T. Z. , Andersen, G. L. , and Knight, R. (2008) Accurate taxonomy assignments from 16S rRNA sequences produced by highly parallel pyrosequencers. *Nucleic Acids Res* 36: 1–11. doi: 10.1093/nar/gkn491.

Loughney, K. , Lund, E. , and Dahlberg, J. E. (1982) tRNA genes are found between 16s and 23s rRNA genes in *Bacillus subtilis*. *Nucleic Acids Res* 10: 1607–1624.

Lovell, C. R. , Friez, J. , Longshore, J. W. , and Bagwell, C. E. (2001) Recovery and phylogenetic analysis of *nifH* sequences from diazotrophic bacteria associated with dead and above ground biomass of *Spartina alterniflora*. *Appl Environ Microbiol* 67: 5308–5314.

Loy, A. , Lehner, A. , Lee, N. , Adamczyk, J. , Meier, H. , Ernst, J. , Schleifer, K. H. , and Wagner, M. (2002) Oligonucleotide microarray for 16S rRNA gene-based detection of all recognized lineages of sulfate-reducing prokaryotes in the environment. *Appl Environ Microbiol* 68: 5064–5081.

Lu, W. (1999) Application of molecular biological techniques to the identification of cyanobacteria. Master's thesis, Liverpool John Moores University, Liverpool, England.

Lu, W. , Evans, E. H. , McColl, S. K. , and Saunders, V. A. (1997) Identification of cyanobacteria by polymorphisms of PCR-amplified ribosomal DNA spacer region. *FEMS Microbiol Lett* 153: 141–149.

Ludwig, W. , and Klenk, H. (2001) Overview: a phylogenetic backbone and taxonomic framework for procaryotic systematics, In: Boone, D. R. , and Castenholz, R. W. (Eds.) *Bergey's Manual of Systematic Bacteriology*, vol. 1. Springer-Verlag, New York, NY, USA. pp. 49–65.

Ludwig, W. , Strunk, O. , Westram, R. , Richter, L. , Meier, H. , Yadhukumar Buchner, A. , Lai, T. , Steppi, S. , Jobb, G. , Förster, W. , Brettske, I. , Gerber, S. , Ginhart, A. W. , Gross, O. , Grumann, S. , Hermann, S. , Jost, R. , König, A. , Liss, T. , Lüßmann, R. , May, M. , Nonhoff, B. , Reichel, B. , Strehlow, R. , Stamatakis, A. , Stuckmann, N. , Vilbig, A. , Lenke, M. , Ludwig, T. , Bode, A. , and Schleifer, K.-H. (2004) ARB: a software environment for sequence data. *Nucleic Acid Res* 32: 1363–1371.

Lyra, C. , Hantula, J. , Vainio, E. , Rapala, J. , Rouhiainen, L. , and Sivonen, K. (1997) Characterization of cyanobacteria by SDS-PAGE of whole-cell proteins and PCR-RFLP of the 16S rRNA gene. *Arch Microbiol* 168: 176–184.

Lyra, C. , Suomalainen, S. , Gugger, M. , Vezie, C. , Sundman, P. , Paulin, L. , and Sivonen, K. (2001) Molecular characterization of planktic cyanobacteria of *Anabaena*, *Aphanizomenon*, *Microcystis* and *Planktothrix* genera. *Int J Syst Evol Microbiol* 51: 513–526.

Maidak, B. L. , Cole, J. R. , Lilburn, T. G. , Parker, C. T. , Jr. , Saxman, P. R. , Farris, R. J. , Garrity, G. M. , Olsen, G. J. , Schmidt, T. M. and Tiedje J. M. (2001) The RDP-II (Ribosomal Database Project). *Nucleic Acids Res* 29: 173–174.

Maiden, M. C. , Bygraves, J. A. , Feil, E. , Morelli, G. , Russell, J. E. , Urwin, R. , Zhang, Q. , Zhou, J. , Zurth, K. , Caugant, D. A. , Feavers, I. M. , Achtman, M. , and Spratt, B. G. (1998) Multilocus sequence typing: a portable approach to the identification of clones within populations of pathogenic microorganisms. *Proc Natl Acad Sci USA* 95: 3140–3145.

Majer, D. , Lewis, B. G. , and Mithen, R. (1998) Genetic variation among field isolates of *Pyrenopeziza brassicae*. *Plant Pathol* 47: 22–28.

Majer, D. , Mithen, R. , Lewis, B. G. , Vos, P. , and Oliver, R. P. (1996) The use of AFLP fingerprinting for the detection of genetic variation in fungi. *Mycol Res* 100: 1107–1111.

Makarova, K. S. , Ponomarev, V. A. and Koonin, E. V. (2001) Two C or not two C: recurrent disruption of Zn-ribbons, gene duplication, lineage-specific gene loss, and horizontal gene transfer in evolution of bacterial ribosomal proteins. *Genome Biol* 2: RESEARCH 0033.

Manichanh, C. , Chapple, C. E. , Frangeul, L. , Gloux, K. , Guigo, R. , and Dore, J. (2008) A comparison of random sequence reads versus 16S rDNA sequences for estimating the biodiversity of a metagenomic library. *Nucleic Acids Res* 36: 5180–5188.

Manichanh, C. , Chapple, C. E. , Frangeul, L. , Gloux, K. , Guigo, R. , and Dore, J. (2008) A comparison of random sequence reads versus 16S rDNA sequences for estimating the biodiversity of a metagenomic library. *Nucleic Acids Res* 36: 5180–5188.

Margulies, M. , Egholm, M. , Altman, W. E. , Attiya, S. , Bader, J. S. , Bemben, L. A. , Berka, J. , Braverman, M. S. , Chen, Y.J. , Chen, Z. , Dewell, S. B. , Du, L. , Fierro, J. M. , Gomes, X. V. , Godwin, B. C. , He, W. , Helgesen, S. , Ho, C. H. , Irzyk, G. P. , Jando, S. C. , Alenquer, M. L. I. , Jarvie, T. P. , Jirage, K. B. , Kim, J-B. , Knight, J. R. , Lanza, J. R. , Leamon, J. H. , Lefkowitz, S. M. , Lei, M. , Li, J. , Lohman, K. L. , Lu, H. , Makhijani, V. B. , McDade, K. E. , McKenna, M. P. , Myers, E. W. , Nickerson, E. , Nobile, J. R. , Plant, R. , Puc, B. P. , Ronan, M. T. , Roth, G. T. , Sarkis, G. J. , Simons, J. F. , Simpson, J. W. , Srinivasan, M. , Tartaro, K. R. , Tomasz, A. , Vogt, K. A. , Volkmer, G. A. , Wang, S. H. , Wang, Y. , Weiner, M. P. , Yu, P. , Begley, R. F. , and Rothberg, J. M. (2005) Genome sequencing in micro-fabricated high-density picolitre reactors. *Nature (London)* 437: 376–380. doi: 10.1038/nature03959

Marsh, T. L. , Saxman, P. , Cole, J. , and Tiedje, J. (2000) Terminal restriction fragment length polymorphism analysis Program, a web-based research tool for microbial community analysis. *Appl Environ Microbiol* 66: 3616–3620.

Martin, W. , and Koonin, E.V. (2006) Introns and the origin of nucleus-cytosol compartmentation. *Nature (London)* 440: 41–45.

Martin, W. , and Muller, M. (1998) The hydrogen hypothesis for the first eukaryote. *Nature (London)* 392: 37–41.

Martin, W. , Rujan, T. , Richly, E. , Hansen, A. , Cornelsen, S. , Lins, T. , Leister, D. , Stoebe, B. , Hasegawa, M. , and Penny, D. (2002) Evolutionary analysis of Arabidopsis, cyanobacterial, and chloroplast genomes reveals plastid phylogeny and thousands of cyanobacterial genes in the nucleus. *Proc Natl Acad Sci USA* 99: 12246–12251.

Martínez-Murcia, A. J. , Acinas, S. G. , and Rodríguez-Valera, F. (1995) Evaluation of prokaryotic diversity by restrictase digestion of 16S rDNA directly amplified from hypersaline environments. *FEMS Microbiol Ecol* 17: 247–255.

Martiny, J. G. H. , Bohannan, B. J. M. , Brown, J. H. , Colwell, R. K. , Fuhrman, J. A. , Green, J. L. , Horner-Devine, M. C. , Kane, M. , Krumins, J. A. , Kuske, C. R. , Morin, P. J. , Naeem, S. , Ørveås, L. , Reysenbach, A-L. , Smith Val, H. , and Staley, J. T. (2006) Microbial biogeography: putting microbes on the map. *Nat Rev Microbiol* 4: 102–112. doi: 10.1038/nrmicro1341

Massol-Deya, A. A. , Odelson, D. A. , Hickey, R. F. , and Tiedje, J. M. (1995) Bacterial community fingerprinting of amplified 16S and 16-23S ribosomal DNA gene sequences and restriction endonuclease analysis (ARDRA). In: Akkermans, A. D. L. , Elsas, J. D. V. , and Bruin, F. J. D. (Eds.) *Molecular Microbial Ecology Manual*. Kluwer Academic Publishers, Dordrecht, Netherlands.

Mayr, E. (1997) *Systematics and the Origin of Species from the Viewpoint of a Zoologist*. Columbia University Press. New York, NY, USA.

Mazard, S. , Fuller, N. J. , Orcutt, K. M. , Bridle, O. , and Scanlan, D. J. (2004) PCR analysis and distribution of unicellular cyanobacterial diazotrophs in the Arabian Sea. *Appl Environ Microbiol* 70: 7355–7364.

Mazel, D. , Houmard, J. , Castets, A. M. , and Tandeau de Marsac, N. (1990) Highly repetitive DNA sequences in cyanobacterial genomes. *J Bacteriol* 172: 2755–2761.

Miller, S. R. , Augustine, S. , Olson, T. L. , Blankenship, R. E. , Selker, J. , and Wood, A. M. (2005) Discovery of a free-living chlorophyll d-producing cyanobacterium with a hybrid proteobacterial/cyanobacterial small-subunit rRNA gene. *Proc Natl Acad Sci USA* 102: 850–855.

Moeseneder, M. M. , Arrieta, J. M. , Muyzer, G. , Winter, C. , and Herndl, G. J. (1999) Optimization of terminal restriction fragment length polymorphism analysis for complex marine bacterioplankton communities and comparison with denaturing gradient gel electrophoresis. *Appl Environ Microbiol* 65: 3518–3525.

Moeseneder, M. M. , Winter, C. , and Herndl, G. J. (2001) Horizontal and vertical complexity of attached and free-living bacteria of the Eastern Mediterranean Sea determined by 16S rDNA and 16S rRNA fingerprints. *Limnol Oceanogr* 46: 95–107.

Moffitt, M. C. , Blackburn, S. I. , and Neilan, B. A. (2001) rRNA sequences reflect the ecophysiology and define the toxic cyanobacteria of the genus *Nodularia*. *Int J Syst Evol Microbiol* 51: 505–512.

Moore, L. R. , and Chisholm, S. W. (1999) Photophysiology of the marine cyanobacterium *Prochlorococcus*: ecotypic differences among cultured isolates. *Limnol Oceanogr* 44: 628–638.

Moore, L. R. , Rocap, G. , and Chisholm, S. W. (1998) Physiology and molecular phylogeny of coexisting *Prochlorococcus* ecotypes. *Nature (London)* 393: 464–467.

Moreira, D. , and Philippe, H. (2000) Molecular phylogeny: pitfalls and progress. *J Theor Biol* 3: 9–16.

Morgan, E. A. , Ikemura, T. , and Nomura, M. (1977) Identification of spacer tRNA genes in individual ribosomal RNA transcription units of *Escherichia coli*. *Proc Natl Acad Sci USA* 74: 2710–2714.

Moyer, C. L. , Dobbs, F. C. , and Karl, D. M. (1994) Estimation of diversity and community structure through restriction fragment length polymorphism distribution analysis of bacterial 16S rRNA genes from a microbial mat at an active, hydrothermal vent system, Loihi seamount, Hawaii. *Appl Environ Microbiol* 60: 871–879.

Murray, R. G. E. , and Schleifer, K. H. (1994) Taxonomic notes: a proposal for recording the properties of putative taxa of procaryotes. *Int J Syst Bacteriol* 44: 174–176.

Muyzer, G. (1999) DGGE/TGGE: a method for identifying genes from natural ecosystems. *Curr Opin Microbiol* 2: 317–322.

Muyzer, G. , de Waal, E. C. , and Uitterlinden, A. G. (1993) Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction-amplified genes coding for 16S rRNA. *Appl Environ Microbiol* 59: 695–700.

Muyzer, G. , Teske, A. , and Wirsén, C. O. (1995) Phylogenetic relationships of *Thiomicrospira* species and their identification in deep-sea hydrothermal vent samples by denaturing gradient gel electrophoresis of 16S rDNA fragments. *Arch Microbiol* 164: 165–172.

Myers, J. L. , Sekar, R. , and Richardson, L. L. (2007) Molecular detection and ecological significance of the cyanobacterial genera *Geitlerinema* and *Leptolyngbya* in Blackband disease of corals. *Appl Environ Microbiol* 73: 5173–5182.

Nakamura, Y. , Itoh, T. , Matsuda, H. , and Gojobori, T. (2004) Biased biological functions of horizontally transferred genes in prokaryotic genomes. *Nat Genet* 36: 760–766.

Nakatsu, C. H. (2007) Soil microbial community analysis using denaturing gradient gel electrophoresis. *Soil Sci Soc Am J* 71: 562–571.

Navarro, E. , Simonet, P. , Normand, P. , and Bardin, R. (1992) Characterization of natural populations of *Nitrobacter* spp. using PCR/RFLP analysis of the ribosomal intergenic spacer. *Arch Microbiol* 157: 107–115.

Nei, M. (1983) Genetic polymorphism and the role of mutation in evolution. In: Koehn, P. K. , and Nei, M. (Eds.) *Evolution of Genes and Proteins*. Sinauer Associates Inc. Publishers, Sunderland, MA, USA. pp. 165–190.

Nei, M. (1984) Genetic polymorphism and neomutationism. In: Mani, G. S. (Ed.) *Evolutionary Dynamics of Genetic Diversity*. Springer-Verlag, New York, NY, USA. pp. 214–241.

Nei, M. (1987) *Molecular Evolutionary Genetics*. Columbia University Press, New York., NY, USA

Nei, M. (2005) Selectionism and neutralism in molecular evolution. *Mol Biol* 22: 2318–2342. doi: 10.1093/molbev/msi242

Nei, M. , and Kumar, S. (2000) *Molecular Evolution and Phylogenetics*. Oxford University Press, New York, NY, USA. pp. 333

Nei, M. , and Rooney, A. P. (2005) Concerted and birth-and-death evolution of multigene families. *Annu Rev Genet* 39: 121–152.

Neilan, B. A. , Jacobs, D. , and Goodman, A. E. (1995) Genetic diversity and phylogeny of toxic cyanobacteria determined by DNA polymorphisms within the phycocyanin locus. *Appl Environ Microbiol* 61: 3875–3883.

Neilan, B. A. , Jacobs, D. , Deldot, T. , Blackall, L. L. , Hawkins, P. R. , Cox, P. T. , and Goodman, A. E. (1997) Ribosomal-RNA sequences and evolutionary relationships among toxic and nontoxic cyanobacteria of the genus *Microcystis*. *Int J Syst Bacteriol* 47: 693–697.

Nelissen, B. , De Baere, R. , Wilmotte, A. , and De Wachter, R. (1996) Phylogenetic relationships of nonaxenic filamentous cyanobacterial strains based on 16S rRNA sequence analysis. *J Mol Evol* 42: 194–200.

Nelissen, B. , Wilmotte, A. , Neefs, J.-M. , and De Wachter, R. (1994) Phylogenetic relationships among filamentous helical cyanobacteria investigated on the basis of 16S ribosomal RNA gene sequence analysis. *Syst Appl Microbiol* 17: 206–210.

Nichols, J. M. , Foulds, I. J. , Crouch, D. H. , and Carr, N. G. (1982) The diversity of cyanobacterial genomes with respect to ribosomal RNA cistrons. *J Gen Microbiol* 128: 2739–2746.

Nishihara, H. , Miwa, H. , Watanabe, M. , Nagashima, M. , Yagi, O. , Takamura, Y. (1997) Random amplified polymorphic DNA (RAPD) analysis for discriminating genotypes of *Microcystis* cyanobacteria. *Biosci Biotechnol Biochem* 61: 1067–1072.

Nishizawa, T. , Asayama, M. , Fujii, K. , Harada, K. , and Shirai, M. (1999) Genetic analysis of the peptide synthetase genes for a cyclic heptapeptide microcystin in *Microcystis* spp. *J Biochem (Tokyo)* 126: 520–529.

Normand, P. , Ponsonnet, C. , Nesme, X. , Neyra, M. , and Simonet, P. (1996) ITS analysis of prokaryotes. In: Akkermans, A. D. L. , van Elsas, J. D. , and de Bruijn, F. J. (Eds.) *Molecular Microbial Ecology Manual*, vol. 3.4.5. Kluwer Academic Publishers, Dordrecht, Netherlands. p. 1–12.

Nübel, U. , De Baere, R. , Wilmotte, A. , and De Wachter, R. (1996) Phylogenetic relationships of nonaxenic filamentous cyanobacterial strains based on the 16S rRNA sequence analysis. *J Mol Evol* 42: 194–200.

Nübel, U. , Garcia-Pichel F. , and Muyzer, G. (1997) PCR primers to amplify 16S rRNA genes from cyanobacteria. *Appl Environ Microbiol* 63: 3327–3332.

Oberholster, P. J. , Botha, A.-M. , Muller, K. , and Cloete, T. E. (2005) Assessment of the genetic diversity of geographically unrelated *Microcystis aeruginosa* strains using amplified fragment length polymorphisms (AFLPs). *Afr J Biotechnol* 4: 389–399.

Ochman, H. , and Moran, N. A. (2001) Genes lost and genes found: evolution of bacterial pathogenesis and symbiosis. *Science* 292: 1096–1099.

Ochman, H. , Lawrence, J. G. , and Groisman, E. A. (2000) Lateral gene transfer and the nature of bacterial innovation. *Nature (London)* 405: 299–304.

Ojaimi, C. , Davidson, B. E. , Saint Girons, I. , and Old, I. G. (1994) Conservation of gene arrangement and an unusual organization of rRNA genes in the linear chromosomes of the Lyme disease spirochaetes *Borrelia burgdorferi*, *B. garinii*, and *B. afzelii*. *Microbiology* 140: 2931–2940.

Olsen, G. J. , Matsuda, H. , Hagstrom, R. and Overbeek, R. (1994) FastDNAml: a tool for construction of phylogenetic trees of DNA sequences using maximum likelihood. *Comput Appl Biosci* 10: 41–48.

Orcutt, K. M. , Rasmussen, U. , Webb, E. A. , Waterbury, J. B. , Gundersen, K. , and Bergman, B. (2002) Characterization of *Trichodesmium* spp. by genetic techniques. *Appl Environ Microbiol* 68: 2236–2245.

Oren, A. (2004) A proposal for further integration of the cyanobacteria under the bacteriological code. *Int J Syst Evol Microbiol* 54: 1895–1902.

Oren, A. (2011) Cyanobacterial systematic and nomenclature as featured in the International Bulletin of Bacteriological Nomenclature and Taxonomy/International Journal of Systematic Bacteriology/International Journal of Systematic and Evolutionary Microbiology. *Int J Syst Evol Microbiol* 61: 10–15.

Oren, A. , and Tindall, B. J. (2005) Nomenclature of the cyanophyta/cyanobacteria/cyanoprokaryotes under the international code of nomenclature of prokaryotes. *Arch Hydrobiol Algol Stud* 117: 39–52.

Osborn, A. M. , Moore, E. R. B. , and Timmis, K. N. (2000) An evaluation of terminal-restriction fragment length polymorphism (T-RFLP) analysis for the study of microbial structure and dynamics. *Environ Microbiol* 2: 39–50.

Otsuka, S. , Suda, S. , Li, R. , Matsumoto, S. , and Watanabe, M. M. (2000) Morphological variability of colonies of *Microcystis* morphospecies in culture. *J Gen Appl Microbiol* 46: 39–50.

Otsuka, S. , Suda, S. , Li, R. , Watanabe, M. , Oyaizu, H. , Matsumoto, S. , and Watanabe, M. M. (1998) 16S rDNA sequences and phylogenetic analyses of *Microcystis* strains with and without phycoerythrin. *FEMS Microbiol Lett* 164: 119–124.

Otsuka, S. , Suda, S. , Li, R. , Watanabe, M. , Oyaizu, H. , Matsumoto, S. , and Watanabe, M. M. (1999) Phylogenetic relationships between toxic and non-toxic strains of the genus *Microcystis* based on 16S to 23S internal transcribed spacer sequence. *FEMS Microbiol Lett* 172: 15–21.

Otsuka, S. , Suda, S. , Shibata, S. , Oyaizu, H. , Matsumoto, S. , and Watanabe, M. M. (2001) A proposal for the unification of five species of the cyanobacterial genus *Microcystis* Kützinger ex Lemmermann 1907 under the Rules of the Bacteriological Code. *Int J Syst Evol Microbiol* 51: 873–879.

Page, R. W. , Jackson, M. J. , and Krassay, A. A. (2000) Constraining sequence stratigraphy in north Australian basins: SHRIMP U-Pb zircon geochronology between Mt Isa and McArthur River. *Aus J Earth Sci* 47: 431–459.

Palenik, B. , and Swift, H. (1996) Cyanobacterial evolution and prochlorophyte diversity as seen in DNA-dependent RNA polymerase gene sequences. *J Phycol* 32: 638–646.

Palinska, K. A. , Liesack, W. , Rhiel, E. and Krumbein, W. E. (1996) Phenotype variability of identical genotypes: the need for a combined approach in cyanobacterial taxonomy demonstrated on Merismopedia-like isolates. *Arch Microbiol* 166: 224–233.

Palinska, K. A. , Thomasius, C. F. , Marquardt, J. , and Golubic, S. (2006) Phylogenetic evaluation of cyanobacteria preserved as historic herbarium exsiccata. *Int J Syst Evol Microbiol* 56: 2253–2263.

Palmer, C. , Bik, E. M. , Eisen, M. B. , Eckburg, P. B. , Sana, T. R. , Wolber, P. K. , Relman, D. A. , and Brown, P. O. (2006) Rapid quantitative profiling of complex microbial populations. *Nucleic Acids Res* 34: e5 doi: 10.1093/nar/gnj007

Pedrés-Alió, C. (2006) Marine microbial diversity: can it be determined? *Trends Microbiol* 14: 257–263.

Pei, A. , Nossa, C. W. , Chokshi, P. , Blaser, M. J. , Yang, L. , Rosmarin, D. M. , and Pei, Z. (2009) Diversity of 23S rRNA genes within individual prokaryotic genomes. *PLoS ONE* 4: e5437. doi: 10.1371/journal.pone.0005437

Pei, A. Y. , Oberdorf, W. E. , Nossam C. W. , Agarwal, A. , Chokshi, P. , Gerz, E. A. , Lee, P. , Yang, L. , Poles, M. , Brown, S. M. , Sotero, S. , DeSantis, T. , Brodie, E. , Nelson, K. , and Pei, Z. (2010) Diversity of 16S rRNA genes within individual prokaryotic genomes. *Appl Environ Microbiol* 76: 3886–3897. doi: 10.1128/AEM.02953-09

Perna, N. T. , Plunkett, G. 3rd , Burland, V. , Mau, B. , Glasner, J. D. , Rose, D. J. , Mayhew, G. F. , Evans, P. S. , Gregor, J. , Kirkpatrick, H. A. et al. (2001) Genome sequence of enterohaemorrhagic *Escherichia coli* O157: H7. *Nature (London)* 409: 529–533.

Persson, P.-E. (1996) Cyanobacteria and off-flavours. *Phycologia* 35: 168–171.

Perumal, G. M. , Ganesan, V. , and Anand, N. (2009) Identification and phylogenetic analysis of filamentous cyanobacteria using random amplified polymorphic DNA (RAPD) finger printing. *Afr J Biotechnol* 8: 974–978.

Pinevich, A. V. (2008) The paradoxes of biodiversity, phylogeny and taxonomy of cyanobacteria. *Moscow Univ Biol Sci Bull* 63: 21–24.

Postius, C. , and Ernst, A. (1999) Mechanisms of dominance: coexistence of picocyanobacterial genotypes in a freshwater ecosystem. *Arch Microbiol* 172: 69–75.

Postius, C. , Ernst, A. , Kenter, U. , and Böger, P. (1996) Persistence and genetic diversity among strains of phycoerythrin-rich cyanobacteria from the picoplankton of Lake Constance. *J Plankton Res* 18: 1159–1166.

Prabina, B. J. , Kumar, K. , and Kannaiyan, S. (2005) DNA amplification fingerprinting as a tool for checking genetic purity of strains in the cyanobacterial inoculum. *World J Microbiol Biotechnol* 21: 629–634. doi:10.1007/s11274-004-3566-5

Rajaniemi, P. , Hrouzek, P. , Kaštovská, K. , Willame, R. , Rantala, A. , Hoffmann, L. , Komárek, J. , and Sivonen, K. (2005) Phylogenetic and morphological evaluation of genera *Anabaena*, *Aphanizomenon*, *Trichormus* and *Nostoc* (Nostocales, Cyanobacteria). *Int J Syst Evol Microbiol* 55: 11–26.

Ramakrishnan, B. , Lueders, T. , Conrad, R. , and Friedrich, M. (2000) Effect of soil aggregate size on methanogenesis and archaeal community structure in anoxic rice field soil. *FEMS Microbiol Ecol* 32: 261–270.

Rasmussen, U. , and Svenning, M. M. (1998) Fingerprinting of cyanobacteria based on PCR with primers derived from short and long tandemly repeated repetitive sequences. *Appl Environ Microbiol* 64: 265–272.

Rastogi, R. , Wu, M. , Das Gupta, I. , and Fox, G. E. (2009) Visualization of ribosomal RNA operon copy number distribution. *BMC Microbiol* 9: 208. doi: 10.1186/1471-2180-9-208

Rippka, R. (1988) Recognition and identification of cyanobacteria. *Methods Enzymol* 167: 28–67.

Rippka, R. , and Cohen-Bazire, G. (1983) The Cyanobacteriales: a legitimate order based on the type strain *Cyanobacterium stanieri*? *Ann Microbiol (Paris)* 134: 21–36.

Rippka, R. , and Herdman, H. (1992) Pasteur Culture Collection of Cyanobacteria: Catalogue and Taxonomic Handbook. I. Catalogue of Strains. Institut Pasteur, Paris.

Rippka, R. , Deruelles, J. , Waterbury, J. B. , Herdman, M. , and Stanier, R. Y. (1979) Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *J Gen Microbiol* 111: 1–61.

Robertson, B. R. , Tezuka, N. , and Watanabe, M. M. (2001) Phylogenetic analyses of *Synechococcus* strains (cyanobacteria) using sequences of 16S rDNA and part of the phycocyanin operon reveal multiple evolutionary lines and reflect phycobilin content. *Int J Syst Evol Microbiol* 51: 861–871.

Robinson, N. J. , Robinson, P. J. , Gupta, A. , Bleasby, A. J. , Whitton, B. A. , and Morby, A. P. (1995) Singular over-representation of an octameric palindrome, HIP1, in DNA from many cyanobacteria. *Nucleic Acids Res* 23: 729–735.

Rocap, G. , Moore, L. R. , and Chisholm, S. W. (1999) Molecular phylogeny of *Prochlorococcus* ecotypes. In: Charpy, L. , and Larkum, A. W. D. (Eds.) *Marine Cyanobacteria*. Bulletin de l'Institut Océanographique, Monaco, Special Issue 19. pp. 107–116.

Rocap, G. , Distel, D. L. , Waterbury, J. B. , and Chisholm, S. W. (2002) Resolution of *Prochlorococcus* and *Synechococcus* ecotypes by using 16S-23S ribosomal DNA internal transcribed spacer sequences. *Appl Environ Microbiol* 68: 1180–1191.

Rosselló-Móra, R. , and Amann, R. (2001) The species concept for prokaryotes. *FEMS Microbiol Rev* 25: 39–67. doi: 10.1111/j.1574-6976.2001.tb00571.x

Rost, B. , and Sander, C. (1996) Bridging the protein sequence-structure gap by structure predictions. *Annu Rev Biophys Biomol Struct* 25: 113–136.

Rouhiainen, L. , Sivonen, K. , Buikema, W. , and Haselkorn, R. (1995) Characterization of toxin-producing cyanobacteria by using an oligonucleotide probe containing a tandemly repeated heptamer. *J Bacteriol* 177: 6021–6026.

Rudi, K. , Skulberg, O. M. , and Jakobsen, K. S. (1998) Evolution of cyanobacteria by exchange of genetic material among phylogenetically related strains. *J Bacteriol* 180: 3453–3461.

Rudi, K. , Skulberg, O. M. , Skulberg, R. , and Jakobsen, K. S. (2000) Application of sequence-specific labeled 16S rRNA gene oligonucleotide probes for genetic profiling of cyanobacterial abundance and diversity by array hybridization. *Appl Environ Microbiol* 66: 4004–4011.

Saitou, W. , and Nei, M. (1987) The neighbor-joining method: A new method for reconstructing phylogenetic trees. *Mol Biol Evol* 4: 406–425.

Saker, M. L. , and Neilan, B. A. (2001) Varied diazotrophies, morphologies and toxicities of genetically similar isolates of *Cylindrospermopsis raciborskii* (Nostocales, Cyanophyceae) from Northern Australia. *Appl Environ Microbiol* 67: 1839–1845.

Sarma, T. A. (1981) Life cycle of *Stichosiphon indica* in cultures. *New Phytol* 88: 103–110.

Scheldeman, P. B. , Baurain, D. , Bouhy, R. , Scott, M. , Muhling, M. , Whitton, B. A. , Belay, A. , and Wilmotte, A. (1999) *Arthrospira* ('*Spirulina*') strains from four continents are resolved into only two clusters, based on amplified ribosomal DNA restriction analysis of the internally transcribed spacer. *FEMS Microbiol Lett* 172: 213–222.

Schmidt, T. M. , DeLong, E. F. , and Pace, N. R. (1991) Analysis of marine picoplankton community by 16S rRNA gene cloning and sequencing. *J Bacteriol* 173: 4371–4378.

Schönhuber, W. , Fuchs, B. , Juretschko, S. , and Amann, R. (1997) Improved sensitivity of whole-cell hybridization by the combination of horseradish peroxidase-labeled oligonucleotides and tyramide signal amplification. *Appl Environ Microbiol* 63: 3268–3273.

Schönhuber, W. , Zarda, B. , Eix, S. , Rippka, R. , Herdman, M. , Ludwig, W. , and Amann, R. (1999) In situ identification of cyanobacteria with Horseradish peroxidase-labeled, rRNA-targeted oligonucleotide probes. *Appl Environ Microbiol* 65: 1259–1267.

Schopf, J. W. (1968) Microflora of the Bitter Springs Formation, Late Precambrian, Central Australia. *J Paleontol* 42: 651–688.

Schopf, J. W. (1993) Microfossils of the Early Archaean Apex Chert: New Evidence of the Antiquity of Life. *Science* 260: 640–646.

Schopf, J. W. and Walter, M. R. (1983) Archean microfossils, new evidence of ancient microbes In: Schopf, J. W. (Ed.) *Earth's Earliest Biosphere: its Origin and Evolution*. Princeton University Press, Princeton, NJ, USA. pp 214–239.

Schopf, J. W. , Kudryavtsev, A. B. , Agresti, D. G. , Wdowiak, T. J. , and Czaja, A. D. (2002) Laser-Raman imagery of Earth's earliest fossils. *Nature* (London) 416: 73–77.

Sen, S. , and Nilsson, L. (1998) Molecular dynamics of duplex systems involving PNA: structural and dynamical consequences of the nucleic acid backbone. *J Am Chem Soc* 120: 619–631.

Sergeev, V. N. (2009) The distribution of microfossil assemblages in Proterozoic rocks. *Precambrian Res* 173: 212–222.

Seo, P.-S. , and Yokota, A. (2003) The phylogenetic relationships of cyanobacteria inferred from 16S rRNA, *gyrB*, *rpoC1* and *rpoD1* gene sequences. *J Gen Appl Microbiol* 49: 191–203.

Sessitsch, A. , Weilharter, A. , Gerzabek, M. H. , Kirchmann, H. , and Kandeler, E. (2001) Microbial population structures in soil particle size fractions of a long-term fertilizer field experiment. *Appl Environ Microbiol* 67: 4215–4224.

Sharma, M. , and Shukla, Y. (2009) The evolution and distribution of life in the Precambrian eon-Global perspective of the Indian record. *J Biosci* 34: 765–776. <http://www.ias.ac.in/jbiosci>

Sharples, G. J. , and Lloyd, R. G. (1990) A novel repeated sequence located in the intergenic regions of bacterial chromosomes. *Nucleic Acids Res* 18: 6503–6508.

Sheldon, P. R. (1987) Parallel gradualistic evolution of Ordovician trilobites. *Nature* (London) 330: 561–563.

Sigler, W.V. , Bachofen, R. , and Zeger, J. (2003) Molecular characterization of endolithic cyanobacteria inhabiting exposed dolomite in central Switzerland. *Environ Microbiol* 5: 618–627.

Skulberg O. M. , and Skulberg, R. (1985) Planktic species of *Oscillatoria* (cyanophyceae) from Norway. *Arch Hydrobiol [Suppl* 71, 1/2] *Algol Stud* 38/39: 157–174.

Small, J. , Call, D. R. , Brockman, F. J. , Straub, T. M. , and Chandler, D. P. (2001) Direct detection of 16S rRNA in soil extracts by using oligonucleotide microarrays. *Appl Environ Microbiol* 67: 4708–4716.

Smith, J. K. , Parry, J. D. , Day, J. G. , and Smith, R. J. (1998) A PCR technique based on HIP1 interspersed repetitive sequence distinguishes cyanobacterial species and strains. *Microbiology* 144: 2791–2801.

Sompong, U. , Anuntalabhochai, S. , Cutler, R. W. , Castenholz, R. W. , and Peerapornpisal, Y. (2008) Morphological and phylogenetic diversity of cyanobacterial populations in six hot springs of Thailand. *ScienceAsia* 34: 153–162.

Song, J. , Lee, S.-C. , Kang, J.W. , Baek, H.-J. , and Suh, J.-W. (2004) Phylogenetic analysis of *Streptomyces* spp. isolated from potato scab lesions in Korea on the basis of 16S rRNA gene and 16S-23S rDNA internally transcribed spacer sequences. *Int J Syst Evol Microbiol* 54: 203–209.

Song, T. , Martensson, L. , Eriksson, T. , Zheng, W. , and Rasmussen, V. (2005) Biodiversity and seasonal variation of the cyanobacterial assemblage in a rice paddy field in Fujian, China. *FEMS Microbiol Ecol* 54: 131–140.

Sorek R , Zhu, Y. , Creevey, C. J. , Francino, M. P. , Bork, P. , and Rubin, E. M. (2007) Genome-wide experimental determination of barriers to horizontal gene transfer. *Science* 318: 1449–1452.

Soria-Carrasco, V. , and Castresana, J. (2008) Estimation of phylogenetic inconsistencies in the three domains of life. *Mol Biol Evol* 25 : 2319–2329.

Sournia, A. (1968) La cyanophyceae *Oscillatoria* (*Trichodesmium*) dans le plancton marin. *Nova Hedwigia* 15: 1–12.

Srivastava, A. K. , and Schlessinger, D. (1990) Mechanism and regulation of bacterial ribosomal RNA processing. *Annu Rev Microbiol* 44: 105–129.

Srivastava, A. K. , Bhargava, P. , Kumar, A. , Rai, L. C. , and Neilan, B. A. (2009) Molecular characterization and the effect of salinity on cyanobacterial diversity in the ricefields of Eastern Uttar Pradesh. *Saline Systems* 5: 4 doi: 10.1186/1746-1448-5-4; <http://www.salinesystems.org/content/5/1/4>.

Srivastava, P. (2005) Vindhyan akinetes: An indicator of Mesoproterozoic biospheric evolution. *Orig Life Evol Biosph* 33: 175–183.

Stackebrandt, E. , and Goebel, B. M. (1994) Taxonomic note: a place for DNA-DNA re-association and 16S rRNA sequence analysis in the present species definition in Bacteriology. *Int J Syst Bacteriol* 44: 846–849.

Stackebrandt, E. , and Ebers J. (2006) Taxonomic parameters revisited: tarnished gold standards. *Microbiol Today* 8: 6–9.

Staley, J. T. (1999) Bacterial biodiversity: a time for place. *ASM News* 10: 1–6.

Staley, J. T. (2006) The bacterial species dilemma and the genomic-phylogenetic species concept. *Phil Trans R Soc B* 361: 1899–1909.

Staley, J. T. , and Gosink, J. J. (1999) Poles apart: biodiversity and biogeography of polar sea ice bacteria. *Annu Rev Microbiol* 53: 189–215. doi: 10.1146/annurev.micro.53.1.189

Stanier, R.Y. , Sistrom, W. R. , Hansen, T. A. , Whitton, B. A. , Castenholz, R. W. , Pfennig, N. , Gorlenko, V. N. , Kondratieva, E. N. , Eimhjellen, K. E. , Whittenbury, R. , Gherna, R. L. , and Trüper, H. G. (1978) Proposal to place nomenclature of the cyanobacteria (blue-green algae) under the rules of the International Code of Nomenclature of Bacteria. *Int J Syst Bacteriol* 28: 335–336.

Stoesser, G. , Baker, W. , van den Broek, A. , Camon, E. , Garcia-Pastor, M. , Kanz, C. , Kulikova, T. , Leinonen, R. , Lin, Q. , Lombard, V. , Lopez, R. , Parkinson, H. et al. (2002) The EMBL nucleotide sequence database. *Nucleic Acids Res* 30: 21–26.

Stulp, B. K. (1983) Morphological and molecular approaches to the taxonomy of the genus *Anabaena* (Cyanophyceae, Cyanobacteria). Drukkerij van Denderen B.V., Groningen, Germany.

Suda, S. , Watanabe, M. M. , Otsuka, S. , Mahakahant, A. , Yongmanitchai, W. , Nopartnaraporn, N. , Liu, Y. , and Day, J. G. (2002) Taxonomic revision of waterbloom forming species of *Oscillatoria* cyanobacteria. *Int J Syst Evol Microbiol* 52: 1577–1595.

Swofford, D. L. , Olsen, G. J. , Waddell, P. J. , and Hillis, D. M. (1996) Phylogenetic inference. In: Hillis, D. M. , Moritz, C. , and Mable, B. K. (Eds.) *Molecular Systematics*. Sinauer, Sunderland, Massachusetts, USA. pp 407–509.

Tanabe, Y. , Kasai, F. , and Watanabe, M. M. (2007) Multilocus sequence typing (MLST) reveals high genetic diversity and clonal population structure of the toxic cyanobacterium *Microcystis aeruginosa*. *Microbiology* 153: 3695–3703.

Taton, A. , Grubisic, S. , Brambilla, E. , De Wit, R. , and Wilmette, A. (2003) Cyanobacterial diversity in natural and artificial microbial mats of Lake Fryxell (McMurdo Dry Valleys, Antarctica): a morphological and molecular approach. *Appl Environ Microbiol* 69: 5157–5169.

Tettelin, H. , Massignani, V. , Cieslewicz, M. J. , Donati, C. , Medini, D. , Ward, N. L. , Angiuoli, S. V. , Crabtree, J. , Jones, A. L. , Durkin, A. S. , DeBoy, R. T. , Davidsen, T. M. , Mora, M. , Scarselli, M. , Ros, I. M. , Peterson, J. D. , Hauser, C. R. , Sundaram, J. P. , Nelson, W. C. , Madupu, R. , Brinkae, L. M. , Dodson, R. J. , Rosovitz, M. J. , Sullivan, S. A. , Daugherty, S. C. , Haft, D. H. , Selengut, J. , Gwinn, G. L. , Zhou, L. , Zafar, N. , Khouri, H. , Radune, D. , Dimitrov, G. , Watkins, K. , O'Connor, K. J. B. , Smith, S. , Utterback, T. R. , White, O. , Rubens, C. E. , Grandi, G. , Madoff, L. C. , Kasper, D. L. , Telford, J. L. , Wessels, M. R. , Rappuoli, R. , and Fraser, C. M. (2005) Genome analysis of multiple pathogenic isolates of *Streptococcus agalactiae*: implications for the microbial 'pangenome'. *Proc Natl Acad Sci USA* 102: 13950–13955.

Thacker, R. W. , and Paul, V. J. (2004) Morphological, chemical and genetic diversity of tropical marine cyanobacteria *Lyngbya* spp. and *Symploca* spp. (Oscillatoriales). *Appl Environ Microbiol* 70: 3305–3312.

Thompson, J. D. , Higgins, D. G. and Gibson, D. J. (1994) CLUSTAL W: improving the sensitivity of progressive multiple sequence alignment. *Comput Appl Biosci* 8: 189–191.

Thuret, G. (1875) Essay de classification des Nostochinées. *Ann Sci Nat* 6: 372–382.

Tiedje, J. M. , Asuming-Brempong, S. , Nusslein, K. , Marsh, T. L. , and Flynn, S. J. (1999) Opening the black box of soil microbial diversity. *Appl Soil Ecol* 13: 109–122.

Tillett, D. , Parker, D. L. , and Neilan, B. A. (2001) Detection of toxigenicity by a probe for the microcystin synthetase a gene (*mcyA*) of the cyanobacterial genus *Microcystis*: comparison of toxicities with 16S rRNA and phycocyanin operon (phycocyanin intergenic spacer) phylogenies. *Appl Environ Microbiol* 67: 2810–2818.

Tindall, B. J. , Rosselló-Móra, R. , Busse, H.-J. , Ludwig, W. , and Kämpfer, P. (2010). Notes on the characterization of prokaryote strains for taxonomic purposes. *Int J Syst Evol Microbiol* 60: 249–266.

Tomioka, N. , and Sugiura, M. (1984) Nucleotide sequence of the 16S-23S spacer region in the *rrnA* operon from a blue-green alga, *Anacystis nidulans*. *Mol Gen Genet* 193: 427–430.

Tomioka, N. , Shinozaki, K. and Sugiura, M. (1981) Molecular cloning and characterization of ribosomal RNA genes from a blue-green alga, *Anacystis nidulans*. *Mol Gen Genet* 184: 359–363.

Tomitani, A. , Knoll, A. H. , Cavanaugh, C. M. , and Ohno, T. (2006) The evolutionary diversification of cyanobacteria: Molecular phylogenetic and palaeontological perspectives. *Proc Natl Acad Sci USA* 103: 5442–5447.

Tringe, S. , von Mering, C. , Kobayashi, A. , Salamov, A. A. , Chen, K. , Chang, H. W. , Podar, M. , Short, J. M. , Mathur, A. J. , Detter, J. C. , Bork, P. , Hugenholtz, P. , and Rubin, E. M. (2005) Comparative metagenomics of microbial communities. *Science* 308: 554–557.

Turner, S. (1997) Molecular systematics of oxygenic photosynthetic bacteria. *Plant Syst Evol* 11: 13–52.

Turner, S. , Huang, T.-C. , and Chaw, S.-M. (2001) Molecular phylogeny of nitrogen fixing unicellular forms. *Bot Bull Acad Sin* 42: 181–186.

Turner, S. , Pryer, K.M. , Miao, V.P. , and Palmer, J.D. (1999) Investigating deep phylogenetic relationships among cyanobacteria and plastids by small subunit rRNA sequence analysis. *J Eukaryot Microbiol* 46: 327–338.

Tyson, G. W. , Chapman, J. , Hugenholtz, P. , Allen, E. E. , Ram, R. J. , Richardson, P. M. , Solovyev, V. V. , Rubin, E. M. , Rokhsar, D. S. , and Banfield, J. F. (2004) Community structure and metabolism through reconstruction of microbial genomes from the environment. *Nature (London)* 428: 37–43.

Urbach, E. , Scanlan, D. J. , Distel, D. L. , Waterbury, J. B. , and Chisholm, S. W. (1998) Rapid diversification of marine picophytoplankton with dissimilar light-harvesting structures inferred from sequences of *Prochlorococcus* and *Synechococcus* (cyanobacteria). *J Mol Evol* 46: 188–201.

Valério, E. , Chambel, L. , Paulino, S. , Fario, N. , Pereira, P. , and Tenreiro, R. (2009) Molecular identification, typing and traceability of cyanobacteria from freshwater reservoir. *Microbiology* 155: 642–656.

Van Gijlswijk, R. P. M. , Wiegant, J. , Raap, A. K. , and Tanke, H. J. (1996) Improved localization of fluorescent tyramides for in situ fluorescence hybridization using dextran sulfate and polyvinyl alcohol. *J Histochem Cytochem* 44: 389–392.

Venter, J. C. , Remington, K. , Heidelberg, J. F. , Halpern, A. L. , Rusch, D. , Eisen, J. A. , Wu, D. , Paulsen, I. , Nelson, K. E. , Nelson, W. , Fouts, D. E. , Levy, S. , Knap, A. H. , Lomas, M. W. , Nealson, K. , White, O. , Peterson, J. , Hoffman, J. , Parsons, R. , Baden-Tillson, H. , Pfannkoch, C. , Rogers, Y.-H. , and Smith, H. O. (2004) Environmental genome shotgun sequencing of the Sargasso Sea. *Science* 304: 66–74.

Vincent, W. F. , Bowman, J. P. , Rankin, L. M. , and McMeekin, T. A. (1999) Phylogenetic diversity of picocyanobacteria in Arctic and Antarctic ecosystems. In: Bell, C. R. , Brylinsky, M. , and Johnson-Green, P. (Eds.) *Microbial Biosystems: New Frontiers: Atlantic Canada Society for Microbial Ecology*, Halifax, Nova Scotia, Canada.

Vinuesa, P. , Rademaker, J. L. W. , De Bruijn, F. J. , and Werner, D. (1998) Genotypic characterization of *Bradyrhizobium* strains nodulating endemic woody legumes of the Canary Islands by PCR-restriction fragment length polymorphism analysis of genes encoding 16S rRNA (16S rDNA) and 16S-23S rDNA intergenic spacers, repetitive extragenic palindromic PCR genomic fingerprinting, and partial 16S rDNA sequencing. *Appl Environ Microbiol* 64: 2096–2104.

Vos, P. , Hogers, R. , Bleeker, M. , Reijans, M. , Van de Lee, T. , Hornes, M. , Frijters, A. , Pot, J. , Peleman, J. , Kuiper, M. , and Zabeau, M. (1995) AFLP: a new technique for DNA fingerprinting. *Nucleic Acids Res* 23: 4405–4414.

Wang, R. F. , Beggs, M. L. , Robertson L. H. and Cerniglia, C. E. (2002) Design and evaluation of oligonucleotide-microarray method for the detection of human intestinal bacteria in fecal samples. *FEMS Microbiol Lett* 213: 175–182.

Wang, R. F. , Beggs, M. L. , Erickson, B. D. and Cerniglia, C. E. (2004) DNA microarray analysis of predominant human intestinal bacteria in fecal samples. *Mol Cell Probes* 18: 223–234.

Ward, D. M. , Ferris, M. J. , Nold, S. C. , Bateson, M. M. , Kopczynski, E. D. , and Ruff-Roberts, A. L. (1994) Species diversity in hot spring microbial mats as revealed by both molecular and enrichment culture approach-relationship between biodiversity and community structure. In: Stal, L. J. , and Caumette, P. (Eds.) *Microbial Mats, Structure, Development and Environmental Significance* (NATO ASI Series, G.35), Springer-Verlag, Heidelberg, Germany pp. 33–44.

Watanabe, M. (1996) Isolation, cultivation, and classification of bloom-forming *Microcystis* in Japan. In: Watanabe, M. F. , Harada, K. , Carmichael, W. W. , and Fukui, H. (Eds.) *Toxic Microcystis*. CRC Press, Boca Raton, FL, USA pp. 13–34.

Wayne, L. G. , Brenner, D. J. , Colwell, R. R. , Grimont, P. A. D. , Kandler, O. , Krichevsky, M. I. , Moore, L. H. , Moore, W. E. C. , Murray, R.G.E. , Stackebrand, E. , Starr, M. P. , and Trüper, H.G. (1987) Report of the ad-hoc committee on reconciliation of approaches to bacterial systematics. *Int J Syst Bacteriol* 37: 463–464.

Waterbury, J. B. , and Rippka, R. (1989) The order Chroococcales. In: Krieg, N. R., and Holt, J. B. (Eds.) *Bergey's Manual of Systematic Bacteriology*, vol. 3. Williams & Wilkins, Baltimore, MD, USA. pp. 1728–1746.

Weiwen, Z. , Tieying, S. , Xiaodong B. , Birgitta, B. , and Ulla, R. (2002) High cyanobacterial diversity in coralloid roots of cycads revealed by PCR fingerprinting. *FEMS Microbiol Ecol* 40: 215–222.

Welsh, J. , and McClelland, M. (1990) Finger printing of genomes using PCR with arbitrary primers. *Nucleic Acids Res* 18: 7213–7218.

West, N. J. , and Adams, D. G. (1997) Phenotypic and genotypic comparison of symbiotic and free-living cyanobacteria from a single field site. *Appl Environ Microbiol* 63: 4479–4484.

West, N. J. , Schönhuber, W. A. , Fuller, N. J. , Amann, R. I. , Rippka, R. , Post, A. F. , and Scanlan, D. J. (2001) Closely related *Prochlorococcus* genotypes show remarkably different depth distributions in two oceanic regions as revealed by in situ hybridization using

16S rRNA-targeted oligonucleotides. *Microbiology* 147: 1731–1744.

Whitman, W. B. , Coleman, D. C. , and Wiebe, W. J. (1998) Prokaryotes: the unseen majority. *Proc Natl Acad Sci USA* 95: 6578–6583.

Whitaker, R. J. (2006) Allopatric origins of microbial species. *Phil Trans R Soc B* 361: 1975–1984.

Whitaker, R. J. , Grogan, D. W. , and Taylor, J. W. (2003) Geographic barriers isolated endemic population of hyperthermophilic archaea. *Science* 301: 976–978. doi: 10.1126/science.1086909.

Whitton, B. A. , and Potts, M. (Eds.) (2000) Introduction to the Cyanobacteria. In: Whitton, B. A. , and Potts, M. (Eds.) *The Ecology of Cyanobacteria: Their Diversity in Time and Space*. Kluwer Academic Publishers, Dordrecht, Netherlands. pp. 1–11.

Wille, N. (1904) Die Schizophyceen der Plankton Expedition. In: Hensen, V. (Ed.) *Ergebnisse der Plankton-Expedition der Humboldt-Stiftung*. Lipsius and Tischer, Kiel, Germany.

Willame, R. , Boute, C. , Grubisic, S. , Komárek, J. , Hoffmann, L. , and Wilmotte, A. (2006) Morphological and molecular characterisation of planktonic cyanobacteria from Belgium and Luxembourg. *J Phycol* 42: 1312–1332.

Wilmotte, A. (1994) Molecular evolution and taxonomy of the cyanobacteria. In: Bryant, D. A. (Ed.) *The Molecular Biology of Cyanobacteria*. Kluwer Academic Publishers, Dordrecht, Netherlands. pp. 1–25.

Wilmotte, A. , and Golubic, S. (1991) Morphological and genetic criteria in the taxonomy of Cyanophyta/Cyanobacteria. *Arch Hydrobiol* 64: 1–24.

Wilmotte, A. , and Herdman, M. (2001) Phylogenetic relationships among the cyanobacteria based on 16S rRNA sequences. In: Garrity, G. M. (Ed.) *Bergey's Manual of Systematic Bacteriology*. Springer-Verlag, New York, NY, USA. pp. 487–493.

Wilmotte, A. M. R. , and Stam, W. T. (1984) Genetic relationships among cyanobacterial strains originally designated as 'Anacystis nidulans' and some other *Synechococcus* strains. *J Gen Microbiol* 130: 2737–2740.

Wilmotte, A. , Neefs, J. M. , and De Wachter, R. (1994) Evolutionary affiliation of the marine nitrogen-fixing cyanobacterium *Trichodesmium* sp. strain NIBB 1067, derived by 16S ribosomal RNA sequence analysis. *Microbiology* 140: 2195–3164.

Wilmotte, A. , Turner, S. , van der Peer, Y. , and Pace, N. R. (1992) Taxonomic study of marine Oscillatorian strains (Cyanobacteria) with narrow trichomes. II. Nucleotide sequence analysis of the 16S ribosomal RNA. *J Phycol* 28: 828–838.

Wilson, K. M. , Schembri, M. A. , Baker, P. D. , and Saint, C. P. (2000) Molecular characterization of the toxic cyanobacterium *Cylindrospermopsis raciborskii* and design of a species-specific PCR. *Appl Environ Microbiol* 66: 332–338.

Wilson, L. A. , and Sharp, M. P. (2006) Enterobacterial repetitive intergenic consensus (ERIC) sequences in *Escherichia coli*: evolution and implications for ERIC-PCR. *Mol Biol Evol* 23: 1156–1168.

Woese, C. R. (1987) Bacterial evolution. *Microbiol Rev* 51: 221–271.

Woese, C. R. , Kandler, O. , and Wheelis, M. (1990) Towards a natural system of organisms. Proposal for the domains Archaea, Bacteria and Eucarya. *Proc Natl Acad Sci USA* 87: 4576–4579.

Wolf, Y. I. , Rogozin, I. B. , Grishin, N. V. , and Koonin, E. V. (2002) Genome trees and the trees of life. *Trends Genet* 18: 472–479.

Worden, A. Z. , Chisholm, S. W. , and Binder, B. J. (2000) In situ hybridization of *Prochlorococcus* and *Synechococcus* (Marine cyanobacteria) spp. with rRNA-targeted peptide nucleic acid probes. *Appl Environ Microbiol* 66: 284–289.

Wright, S. (1931) Evolution in Mendelian populations. *Genetics* 16: 97–159.

Wu, Z. , Shi, J. , and Li, R. (2010) Unraveling molecular diversity and phylogeny of *Aphanizomenon* (Nostocales, Cyanobacteria) strains isolated from China. *J Phycol* 46: 1048–1058.

Wuyts, J. , De Rijk, P. , Van de Peer, Y. , Winkelmans, T. and De Wachter, R. (2001) The European Large Subunit Ribosomal RNA Database. *Nucleic Acids Res* 29: 175–177.

Wuyts, J. , Van de Peer, Y. , Winkelmans, T. and De Wachter, R. (2002) The European database on small subunit ribosomal RNA. *Nucleic Acids Res* 30: 183–185.

Xu, D. , and Cote, J.-C. (2003) Phylogenetic relationships between *Bacillus* species and related genera inferred from comparison of 3'-end 16S rDNA and 5'-end 16S-23S ITS nucleotide sequences. *Int J Syst Evol Microbiol* 53: 695–704.

Yap, W.H. , Zhang, Z. , and Wang, Y. (1999) Distinct types of rRNA operons exist in the genome of the actinomycete *Thermomonospora chromogena* and evidence for horizontal transfer of an entire rRNA operon. *J Bacteriol* 181: 5201–5209.

Yeager, C. M. , Kornosky, J. L. , Morgan, R. E. , Cain, E. C. , Garcia-Pichel, F. , Housman, D. C. , Belnap, J. , and Kuske, C. R. (2007) Three distinct clades of cultured heterocystous cyanobacteria constitute the dominant N₂-fixing members of biological soil crusts of the Colorado Plateau, USA. *FEMS Microbiol Ecol* 60: 85–97.

Zehr, J. P. , Limburger, R. J. , Ohki, K. , and Fujita, Y. (1990) Antiserum to nitrogenase generated from an amplified DNA fragment from natural populations of *Trichodesmium* spp. *Appl Environ Microbiol* 56: 3527–3531.

Zehr, J. P. , Mellon, M. T. , and Hiorns, W. D. (1997) Phylogeny of cyanobacterial *nifH* genes: evolutionary implications and potential applications to natural assemblages. *Microbiology (Reading)* 143: 1443–1450.

Zeigler, D. R. (2003) Gene sequences useful for predicting relatedness of whole genomes in bacteria. *Int J Syst Evol Microbiol* 53: 1893–1900. doi: 10.1099/ijs.0.02713-0

Zhaxybayeva, O. , Lapierre, P. , and Gogarten, J. P. (2004) Genome mosaicism and organismal lineages. *Trends Genet* 20: 254–260.

Zhaxybayeva, O. , Gogarten, J. P. , Charlebois, R. L. , Doolittle, W. F. , and Papke, R. T. (2006) Phylogenetic analyses of cyanobacterial genomes: quantification of horizontal transfer events. *Genome Res* 16: 1099–1108. doi: 10.1101/gt.5322306

Zhaxybayeva, O. , Doolittle, W. F. , Papke, R. T. , and Gogarten, J. P. (2009) Intertwined evolutionary histories of marine *Synechococcus* and *Prochlorococcus marinus*. *Genome Biol Evol* 1: 325–339. doi: 10.1093/gbe/evp032

Zuckerkandl, E. , and Pauling, L. (1965) Evolutionary divergence and convergence in proteins. In: Bryson, V. , and Vogel, H. J. (Eds.) *Evolving Genes and Proteins*. Academic Press, New York, NY, USA. pp. 97–166.

Chapter Genomes

Ahmed, N. (2009) A flood of microbial genomes-do we need more? *PLoS ONE* 4: e5831. doi:<https://doi.org/10.1371/journal.pone.0005831>

Akiyama, M. , Gotoh, T. , Kise, H. , Miyashita, H. , Mimuro, M. , and Kobayashi, M. (2004) Stoichiometries of chlorophyll d/PSI and chlorophyll a/PSII in a chlorophyll d-dominated cyanobacterium *Acaryochloris marina*. *Jpn J Phycol* 52: 67-72.

Akiyama, M. , Miyashita, H. , Kise, H. , Watanabe, T. , Miyachi, S. , and Kobayashi, M. (2001) Detection of chlorophyll d and pheophytin a in a chlorophyll d-dominating oxygenic photosynthetic prokaryote *Acaryochloris marina*. *Anal Sci* 17: 205-208.

Akiyama, M. , Miyashita, H. , Kise, H. , Watanabe, T. , Mimuro, M. , Miyachi, S. , and Kobayashi, M. (2002) Quest for minor but key chlorophyll molecules in photosynthetic reaction centers-unusual pigment composition in the reaction centers of the chlorophyll d-dominated cyanobacterium *Acaryochloris marina*. *Photosynth Res* 74: 97-107.

Allen, J. F. , de Paula, W. B. M. , Puthiyaveetil, S. , and Nield, J. (2011) A structural phylogenetic map for chloroplast photosynthesis. *Trends Plant Sci* 16: 645-655.

Almeida, L. G. P. , Paixao, R. , Souza, R.C. , da Costa, G. C. , Barrientos, F. J. , dos Santos, M. T. , de Almeida, D.F. , and Vasconcelos, A. T. R. (2004) A system for automated bacterial (genome) integrated annotation-SABIA. *Bioinformatics* 20: 2832-2833.

Altschul, S. F. , and Koonin, E. V. (1998) Iterated profile searches with PSI-BLAST: a tool for discovery in protein databases. *Trends Biochem Sci* 23: 494-497.

Altschul, S. F. , Gish, W. , Miller, W. , Myers, E. W. , and Lipman, J. (1990) Basic local alignment tool. *J Mol Biol* 215: 403-410. doi: <https://doi.org/10.1006/mbi.1990.9999>

Altschul, S. F. , Madden, T. L. , Schaffer, A. A. , Zhang, J. , Zheng, Z. , Miller, W. , and Lipman, D. J. (1997) Gapped BLAST and PSI-BLAST—a new generation of protein database search programs. *Nucleic Acids Res* 25: 3389-3402.

Amunts, A. , Drory, O. , and Nelson, N. (2007) The structure of a plant photosystem I supercomplex at 3.4 Å resolution. *Nature (London)* 447: 58-63.

Awai, K. , Kakimoto, T. , Awai, C. , Kaneko, T. , Nakamura, Y. , Takamiya, K-i. , Wada, H. , and Ohta, H. (2006) Comparative genomic analysis revealed a gene for monoglucosyldiacylglycerol synthase, an enzyme for photosynthetic membrane lipid synthesis in cyanobacteria. *Plant Physiol* 141: 1120-1127.

Axmann, I. M. , Kensche, P. , Vogel, J. , Kohl, S. , Herzel, H. , and Hess, W. R. (2005) Identification of cyanobacterial non-coding RNAs by comparative genome analysis. *Genome Biol* 6: R73. doi:<https://doi.org/10.1186/gb-2005-6-9-r73>

Badger, J. H. , and Olsen, G. J. (1999) CRITICA: Coding region identification tool invoking comparative analysis. *Mol Biol Evol* 16: 512-524.

Bazzan, A. L. C. , Duarte, R. , Pitinga, A. N. , Schroeder, L. F. , Souto, F. D. A. , and Ceroni da Silva, S. (2003) ATUGC—an agent-based environment for automatic annotation of genomes. *Int J Comp Inform Syst* 12: 241-273.

Belda, E. , Moya, A. , and Silva, F. J. (2005) Genome rearrangement distances and gene order phylogeny in {gamma} proteobacteria. *Mol Biol Evol* 22: 1456-1467.

Bergman, N. H. , Passalacqua, K. D. , Hanna, P. C. , and Qin, Z. S. (2007) Operon prediction for sequenced bacterial genomes without experimental information. *Appl Environ Microbiol* 73: 846-854. doi: <https://doi.org/10.1128/AEM.01686-06>

Bhaya, D. , Dufresne, A. , Vulot, D. , and Grossman, A. (2002) Analysis of hli gene family in marine and freshwater cyanobacteria. *FEMS Microbiol* 215: 209-219.

Biers, E. J. , Sun, S. , and Howard, E. C. (2009) Prokaryotic genomes and diversity in surface ocean waters: Integrating the global ocean sampling metagenome. *Appl Environ Microbiol* 75: 2221-2229. doi:<https://doi.org/10.1128/AEM02118-08>

Blanchette, M. , Kunisawa, T. , and Sankoff, D. (1999) Gene order break point evidence in animal mitochondrial phylogeny. *J Mol Evol* 49: 193-203.

Blattner, F. R. , Plunkett, G. III. , Bloch, C. A. , Perna, N. T. , Burland, V. , Riley, M. , Collado-Vides, J. , Glasner, J. D. , Rode, C. K. , Mayhew, G. , Gregor, J. , Davis, N. W. , Kirkpatrick, H. A. , Goeden, M. A. , Rose, D. J. , Man, B. , and Shao, Y. (1997) The complete genome sequence of *Escherichia coli* K-12. *Science* 277: 1453-1462.

Bryson, K. , Loux, V. , Bossy, R. , Nicolas, P. , Chaillou, S. , van de Guchte, M. , Penaud, S. , Maguin, E. , Hoebeke, M. , Bessi res, P. , and Gibrat, J-F. (2006) AGMIAL: Implementing an annotation strategy for prokaryotic genomes as a distributed system. *Nucleic Acids Res* 34: 3533-3545. doi: <https://doi.org/10.1093/nar/gk1471>

Campbell, E. L. , Brahamsha, B. , and Meeks, J. C. (1998) Mutation of an alternative sigma factor in the cyanobacterium *Nostoc punctiforme* results in increased infection of its symbiotic plant partner, *Anthoceros punctatus*. *J Bacteriol* 180: 4938-4941.

Cadel-Six, S. , Iteaman, I. , Peyraud-Thomas, C. , Mann, S. , Ploux, O. , and M jean, A. (2009) Identification of a polyketide synthase coding sequence specific for anatoxin-a-producing *Oscillatoria* cyanobacteria. *Appl Environ Microbiol* 75: 4909-4912.

Chen, X. , Su, Z. , Dam, P. , Palenik, P. , Xu, Y. , and Jiang, T. (2004) Operon prediction by comparative genomics: An application to the *Synechococcus* sp. WH8102 genome. *Nucleic Acids Res* 32: 2147-2157. doi: <https://doi.org/10.1093/nar/gkh510>

Chi, X. , Yang, Q. , Zhao, E. , Qin, S. , Yang, Y. , Shen, J. , and Lin, H. (2008) Comparative analysis of fatty acid desaturases in cyanobacterial genomes. *Comp Funct Genomics* 2008. Article Id:284508. doi:<https://doi.org/10.1155/2008/284508>

Coleman, M. , Sullivan, M. B. , Martiny, A. C. , Steglich, C. , Barry, K. , DeLong, E. F. , and Chisholm, S. W. (2006) Genomic islands and the ecology and evolution of *Prochlorococcus*. *Science* 311: 1768-1770. doi:<https://doi.org/10.1126/science.1122050>

Craven, M. , Page, D. , Shavlik, J. , Bockhorst, J. , and Glasner, J. (2000) A probabilistic learning approach to whole-genome operon prediction. *Proc 8th Internl Conf on Intelligent Systems for Molecular Biology*, AAAI Press, San Diego, CA, USA pp. 116-127.

Csiszar, K. , Houmard, J. , Damerval, T. , and Tandeau de Marsac, N. (1987) Transcriptional analysis of the cyanobacterial *gvpABC* operon in differentiated cells: Occurrence of an antisense RNA complementary to three overlapping transcripts. *Gene* 60: 29-37.

Dam, P. , Oltman, V. , Harris, K. , Su, Z. , and Xu, Y. (2007) Operon prediction using both genome-specific and general genome information. *Nucleic Acids Res* 35: 288-298. doi:<https://doi.org/10.1093/nar/gkl1018>

Dietz, K. J. (2003) Plant peroxiredoxins. *Annu Rev Plant Biol* 54: 93-107.

Dolganov, N. A. M. , Bhaya, D. , and Grossman, A. R. (1995) Cyanobacterial protein with similarity to the chlorophyll a/b-binding proteins of higher plants: Evolution and regulation. *Proc Natl Acad Sci USA* 92: 636-640.

Domain, F. , Houot, L. , Chauvat, F. , and Cassier-Chauvat, C. (2004) Function and regulation of the cyanobacterial genes *lexA*, *recA* and *ruvB*: LexA is critical to the survival of cells facing inorganic carbon starvation. *Mol Microbiol* 53: 65-80.

Doolittle, R. F. (Ed.) (1996) *Computer Methods for Macromolecular Sequence Analysis*. *Methods Enzymol* 266. Academic Press, San Diego, CA, USA.

Ducret, A. , Muller, S. A. , Goldie, K. N. , Hefti, A. , Sidler, W. A. , Zuber, H. , and Engel, A. (1998) Reconstitution, characterisation and mass analysis of the pentacylindrical allophycocyanin core complex from the cyanobacterium *Anabaena* sp. PCC 7120. *J Mol Biol* 278: 369-388.

Dufresne, A. , Garczarek, L. , and Partensky, F. (2005) Accelerated evolution associated with genome reduction in a free-living prokaryote. *Genome Biol* 6: R14. <http://genomebiology.com/2005/6/2/R14>

Dufresne, A. , Salanoubat, M. , Partensky, F. , Artiguenave, F. , Axmann, I. M. , Barbe, V. , Duprat, S. , Galperin, M. Y. , Koonin, E. V. , Le Gall, F. , Makarova, K. S. , Ostrowski, M. , Oztas, S. , Robert, C. , Rogozin, I. B. , Scanlan, D. J. , Tandeau de Marsac, N. , Weissenbach, J. , Wincker, P. , Wolf, Y. I. , and Hess, W. R. (2003) Genome sequence of the cyanobacterium *Prochlorococcus marinus* SS120, a nearly minimal oxyphototrophic genome. *Proc Natl Acad Sci USA* 100: 10020-10025.

Dufresne, A. , Ostrowski, M. , Scanlan, D. J. , Garczarek, L. , Mazard, S. , Palenik, B. P. , Paulsen, I. T. , Tandeau de Marsac, N. , Wincker, P. , Dossat, C. , Ferriera, S. , Johnson, J. , Post, A. F. , Hess, W. R. , and Partensky, F. (2008) Unraveling the genome mosaic of a ubiquitous genes of marine cyanobacteria. *Genome Biol* 9: R90. doi:<https://doi.org/10.1186/gb-2008-9-5-r90>

Duhring, U. , Axmann, I. M. , Hess, W. R. , and Wilde, A. (2006) An internal antisense RNA regulates expression of the photosynthesis gene *isiA*. *Proc Natl Acad Sci USA* 103: 7054-7058.

Elhai, J. , Kato, M. , Cousins, S. , Lindblad, P. , and Costa, J. L. (2008) Very small mobile repeated elements in cyanobacterial genomes. *Genome Res* 18: 1484-1499. doi:<https://doi.org/10.1101/gr.074336.107>

Ermolaeva, M. D. , White, O. , and Salzberg, S. L. (2001) Prediction of operons in microbial genomes. *Nucleic Acids Res* 29: 1216-1221.

Fernandez De Henestrosa, A. R. , Ogi, T. , Aoyagi, S. , Chafin, D. , Hayes, J. J. , Ohmori, H. , and Woodgate, R. (2000) Identification of additional genes belonging to the LexA regulon in *Escherichia coli*. *Mol Microbiol* 35: 1560-1572.

Fitch, W. M. (1970) Distinguishing homologous from analogous proteins. *Syst Zool* 19: 99-113.

Fleischmann, R. D. , Adams, M. D. , White, O. , Clayton, R. A. , Kirkness, E. F. , Kerlavage, A. R. , Bult, C. J. , Tomb, B. A. , Dougherty, B. A. , Merrik, J. , McKenney, K. , Sutton, G. , FitzHugh, W. , Fields, C. , Gocayne, D. , Scott, J. , Shirley, R. , Liu, L.-I. , Glodek, A. , Kelley, J. M. , Weidman, J. F. , Phillips, C. A. , Spriggs, T. , Hedblorn, E. , Cotton, M. D. , Utterback, T. R. , Hanna, M. C. , Nguyen, D. T. , Saudek, D. M. , Brandon, R. C. , Fine, L. D. , Fritchman, J. L. , Fuhrmann, J. L. , Geoghagen, N. S. M. , Gnehm, C. L. , McDonald, L. A. , Small, K. V. , Fraser, C. M. , Smith, H. O. , and Venter, J. C. (1995) Whole-genome random sequencing and assembly of *Haemophilus influenzae* Rd. *Science* 269: 496-512.

Frangeul, L. , Quillardet, P. , Castets, A. M. , Humbert, J-F. , Matthijs, H. C. P. , Cortez, D. , Tolonen, A. , Zhang, G-C. , Gribaldo, S. , Kehr, J-C. , Zilliges, Y. , Ziemert, N. , Becker, S. , Talla, E. , Latifi, A. , Billault, A. , Lepelletier, A. , Dittmann, E. , Bouchier, C. , and Tandeau de Marsac, N. (2008) Highly plastic genome of *Microcystis aeruginosa* PCC 7806, a ubiquitous toxic freshwater cyanobacterium. *BMC Genomics* 9: 274 doi:<https://doi.org/10.1186/1471-2164-9-274>

Frias-Lopez, J. , Shi, Y. , Tyson, G. W. , Coleman, M. L. , Schuster, S. C. , Chisholm, S. W. , and De Long, E. F. (2008) Microbial community gene expression in ocean surface waters. *Proc Natl Acad Sci USA* 105: 3805-3810. doi:<https://doi.org/10.1073/nas.0708897105>

Fujisawa, T. , Narikawa, R. , Okamoto, S. , Ehira, S. , Yoshimura, H. , Suzuki, I. , Masuda, T. , Mochimaru, M. , Takaichi, S. , Awai, K. , Sekine, M. , Horikawa, H. , Yashiro, I. , Omata, S. , Takarada, H. , Katano, Y. , Kosugi, H. , Tanikawa, S. , Ohmori, K. , Sato, N. , Ikeuchi, M. , Fujita, N. , and Ohmori, M. (2010) Genomic structure of an economically important cyanobacterium, *Arthrospira* (*Spirulina*) *platensis* NIES-39. *DNA Res* 17: 85-103. doi:<https://doi.org/10.1093/dnares/dsq004>

Fuller, N. J. , Marie, D. , Partensky, F. , Vaultot, D. , Post, A. F. , and Scanlan, D. J. (2003) Clade-specific 16S ribosomal DNA oligonucleotides reveal the predominance of a single marine *Synechococcus* clade throughout a stratified water column in the Red Sea. *Appl Environ Microbiol* 69: 2430-2443.

Funk, C. , and Vermaas, W. (1999) A cyanobacterial gene family coding for single-helix proteins resembling part of the light-harvesting proteins from higher plants. *Biochemistry* 38: 9397-9404.

Gaasterland, T. , and Sensen, C. W. (1996) Fully automated genome analysis that reflects user needs and preferences. A detailed introduction to the MAGPIE system architecture. *Biochimie* 78: 302-310.

Gardian, Z. , Bumba, L. , Schrofel, A. , Herbstova, M. , Nebesarova, J. , and Vacha, F. (2007) Organization of photosystem I and photosystem II in red alga *Cyanidium caldarium* encounter of cyanobacterial and higher plant concepts. *Biochim Biophys Acta* 1767: 725-731.

Gerdes, S. Y. , Kurnasov, O. V. , Shatalin, K. , Polanuyer, B. , Sloutsky, R. , Vonstein, V. , Overbeek, R. , and Osterman, A. L. (2006) Comparative genomics of NAD biosynthesis in cyanobacteria. *J Bacteriol* 188: 3012-3023. doi:<https://doi.org/10.1128/jb.188.8.3012-3023.2006>

Glazer, A. N. , Williams, R. C. , Yeh, S. W. , and Clark, J. H. (1985) Kinetics of energy flow in the phycobilisome core. *Science* 230: 1051-1053.

Gombos, Z. , Kanervo, E. , Tsvetkova, N. , Sakamoto, T. , Aro, E.-M. , and Murata, N. (1997) Genetic enhancement of the ability to tolerate photoinhibition by introduction of unsaturated bonds into membrane glycerolipids, *Plant Physiol* 115: 551-559.

Grigoriev, A. (1998) Analyzing genomes with cumulative skew diagrams. *Nucleic Acids Res* 26: 2286-2290.

Guan, X. , Qin, S. , Zhao, F. , Zhang, X. , and Tang, X. (2007) Phycobilisomes linker family in cyanobacterial genomes: Divergence and evolution. *Int J Biol Sci* 3: 434-445. www.biolsci.org.

Gupta, R. S. (2009) Protein signatures (molecular synapomorphies) that are distinctive characteristics of the major cyanobacterial clades. *Int J Syst Evol Microbiol* 59: 2510-2526. doi:<https://doi.org/10.1099/ijs.0.005678-0>

Gutekunst, K. , Phunpruch, S. , Schwarz, C. , Schuchardt, S. , Schulz-Friedrich, R. , and Appel, J. (2005) LexA regulates the bidirectional hydrogenase in the cyanobacterium *Synechocystis* sp. PCC 6803 as a transcription activator. *Mol Microbiol* 58: 810-823.

Henikoff, S. , and Henikoff, J. G. (1997) Embedding strategies for effective use of information from multiple sequence alignments. *Protein Sci* 6: 698-705.

Herdman, M. , Janvier, M. , Rippka, R. , and Stanier, R. Y. (1979) Genome size of cyanobacteria. *J Gen Microbiol* 111: 73-85.

Hernandez, J. A. , Muro-Pastor, A. M. , Flores, E. , Bes, M. T. , Peleato, M. L. , and Fillat, M. F. (2006) Identification of a *furA* cis antisense RNA in the cyanobacterium *Anabaena* sp. PCC 7120. *J Mol Biol* 355: 325-334.

Herrero, A. , Muro-Pastor, A. M. and Flores, E. (2001) Nitrogen control in cyanobacteria. *J Bacteriol* 183: 411-425.

Hirani, T. A. , Suzuki, I. , Murata, N. , Hayashi, H. , and Eaton-Rye, J. J. (2001) Characterization of a two-component signal transduction system involved in the induction of alkaline phosphatase under phosphate-limiting conditions in *Synechocystis* sp. PCC 6803. *Plant Mol Biol* 45: 133-144.

Hofmann, B. , Hecht, H. J. , and Flohe, L. (2002) Peroxiredoxins. *Biol Chem* 383: 347-364.

Janssen, P. J. , Morin, N. , Mereay, M. , Leroy, B. , Wattiez, R. , Vallaes, T. , Waleron, K. , Waleron, M. , Wilmotte, A. , Quillardet, P. , Tandeau de Marsac, N. , Talla, E. , Zhang, C.-C. , and Leys, N. (2010) Genome sequence of the edible cyanobacterium *Arthrospira* sp. PCC 8005. *J Bacteriol* 192: 2465-2466.

Johnson, Z. I. , and Chisholm, S. W. (2004) Properties of overlapping genes are conserved across microbial genomes. *Genome Res* 14: 2268-2272. doi:<https://doi.org/10.1101/gr.2433104>.

Jones, A. , Manroe, E. A. , Podell, S. , Hess, W. R. , Klages, S. , Esquenzi, E. , Niessen, S. , Hoover, H. , Rothmann, M. , Lasken, R. S. , Yates III. J. R. , Reinhardt, R. , Kube, M. , Burkart, M. D. , Allen, E. E. , Dorrestein, P. C. , Gerwick, W. H. , and Gerwick, L. (2011) Genomic insights into physiology and ecology of the marine filamentous cyanobacterium, *Lyngbya majuscula*. *Proc Natl Acad USA* 108: 8815-8820. doi:<https://doi.org/10.1073/pnas.11011137108>.

Jordan, P. , Fromme, P. , Witt, H. T. , Klukas, O. , Saenger, W. , and Krauss, N. (2001) Three-dimensional structure of cyanobacterial photosystem I at 2.5 Å resolution. *Nature (London)* 411: 909-917.

Kaneko, T. , Nakajima, N. , Okamoto, S. , Suzuki, I. , Tanabe, Y. , Tamaoki, M. , Nakamura, Y. , Kasi, F. , Watanabe, A. , Kawashima, K. , Kishida, Y. , Ono, Y. , Shimizu, Y. , Takahashi, C. , Minami, C. , Fujishiro, T. , Kohara, M. , Katoh, M. , Nakazaki, N. , Nakayama, S. , Yamada, M. , Tabata, S. , and Watanabe, M. M. (2007) Complete genomic structure of the bloom-forming toxic cyanobacterium *Microcystis aeruginosa* NIES-843. *DNA Res* 14: 247-256.

Kaneko, T. , Nakamura, Y. , Sasamoto, S. , Watanabe, A. , Kohara, M. , Matsumoto, M. , Shimpo, S. , Yamada, M. , and Tabata, S. (2003) Structural analysis of four large plasmids harboring in a unicellular cyanobacterium *Synechocystis* sp. PCC 6803. *DNA Res* 10: 221-228.

Kaneko, T. , Nakamura, Y. , Wolk, C. P. , Sasamoto, S. , Watanabe, A. , Iriguchi, M. , Ishikawa, A. , Kawashima, K. , Kimura, T. , Kishida, Y. , Kohara, M. , Matsumoto, M. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Shimpo, S. , Sugimoto, M. , Takazawa, M. , Yamada, M. , Yasuda, M. , and Tabata, S. (2001) Complete genomic sequence of the filamentous nitrogen-fixing cyanobacterium *Anabaena* sp. strain PCC 7120. *DNA Res* 8: 205-213.

Kaneko, T. , Sato, S. , Kotani, H. , Tanaka, A. , Asamizu, E. , Nakamura, Y. , Miyajima, N. , Hirose, M. , Sugiura, M. , Sasamoto, S. , Kimura, T. , Hosouchi, T. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Naruo, K. , Okumura, S. , Shimpo, S. , Takeuchi, C. , Wada, T. , Watanabe, A. , Yamada, M. , Yasuda, M. , and Tabata, S. (1996) Sequence analysis of the genome of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. II. Sequence determination of the entire genome and assignment of potential protein-coding regions. *DNA Res* 3: 109-136.

Kaneko, T. , Tanaka, A. , Sato, S. , Kotani, H. , Sazuka, T. , Miyajima, N. , Sugiura, M. , and Tabata, S. (1995) Sequence analysis of the genome of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. I. Sequence features in the 1 Mb region from map positions 64% to 92% of the genome. *DNA Res* 2: 153-166.

Kasahara, M. , and Ohmori, M. (1999) Activation of a cyanobacterial adenylate cyclase, CyaC, by autophosphorylation and a subsequent phosphotransfer reaction. *J Biol Chem* 274: 15167-15172.

Katayama, M. , and Ohmori, M. (1997) Isolation and characterization of multiple adenylate cyclase genes from the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 179: 3588-3593.

Kaufmann, M. (2006) The role of COG database in comparative and functional genomics. *Curr Bioinformatics* 1: 291-300.

Kettler, J. C. , Martiny, A. C. , Huang, K. , Zucker, J. , Coleman, M. L. , Rodrigue, S. , Chen, F. , Lapidus, A. , Ferreira, S. , Johnson, J. , Steglich, C. , Church, G. M. , Richardson, P. , and Chisholm, S. W. (2007) Patterns and implications of gene gain and loss in the evolution of *Prochlorococcus*. *PLoS Genet* 3: e231. doi:<https://doi.org/10.1371/journal.pgen.0030231>

Kotani, H. , Kaneko, T. , Matsubayashi, T. , Sato, S. , Sugiura, M. , and Tabata, S. (1994) A physical map of the genome of a unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. *DNA Res* 1: 303-307.

Koonin, E. V. , and Galperin, M. Y. (1997) Prokaryotic genomes: The emerging paradigm of genome-based microbiology. *Curr Opin Genet Develop* 7: 757-763.

Koonin, E. V. , Tatusov, R. L. , and Galperin, M. Y. (1998) Beyond complete genomes: From sequence to structure and function. *Curr Opin Struct Biol* 8: 355-363.

Konstantinidis, K. T. , and Tiedje, J. M. (2005) Genomic insights that advance the species definition for prokaryotes. *Proc Natl Acad Sci USA* 102: 2567-2572.

Kühl, M. , Chen, M. , Ralph, P. J. , Schreiber, U. , and Larkum, A. W. D. (2005) A niche for cyanobacteria containing chlorophyll d. *Nature (London)* 433: 820

Li, S. , Xu, M. , and Su, Z. (2010) Computational analysis of LexA regulons in cyanobacteria. *BMC Genomics* 11: 527. doi:<https://doi.org/10.1186/1471-2164-11-527>

Lombardot, T. , Kottmann, R. , Pfeffer, H. , Richter, M. , Teeling, H. , Quast, C. , and Glöckner, F. O. (2006) Megx.net-database resources for marine ecological genomics. *Nucleic Acids Res* 34: D390-D393 doi: <https://doi.org/10.1093/nar/gkj070>

Luo, H. , Shi, J. , Arndt, W. , Tang, J. , and Friedman, R. (2008) Gene order phylogeny of the genus *Prochlorococcus*. *PLoS ONE* 3: e3837.

Markov, A. V. , and Zakharov, I. A. (2009) Evolution of gene orders in genomes of cyanobacteria. *Russian J Genet* 45: 906-916.

Markowitz, V. M. , Mavromatis, K. , Ivanova, N. N. , Chen, I-M. A. , Chu, K. , and Kyrpides, N. C. (2009) IMG-ER: A system for microbial genome annotation expert review and curation. *Bioinformatics* 25: 2271-2278.

Mazmouz, R. , Chapuis-Hugon, F. , Mann, S. , Pichon, V. , Méjean, A. , and Ploux, O. (2010) Biosynthesis of cylindrospermopsin and 7-epicylindrospermopsin in *Oscillatoria* PCC 6506; identification of the gene cluster and toxin analysis. *Appl Environ Microbiol* 76: 4943-4949.

Mazon, G. , Erill, I. , Campoy, S. , Cortes, P. , Forano, E. , and Barbe, J. (2004) Reconstruction of the evolutionary history of the LexA-binding sequence. *Microbiology* 150: 3783-3795.

Medigue, C. , Rechenmann, F. , Danchin, A. , and Viari, A. (1999) Imagine: An integrated computer environment for sequence annotation and analysis. *Bioinformatics* 15: 2-15.

Meeks, J. C. , Elhai, J. , Thiel, T. , Potts, M. , Larimer, F. , Lamerdin, J. , Predki, P. , and Atlas, R. (2001) An overview of the genome of *Nostoc punctiforme*, a multicellular symbiotic cyanobacterium. *Photosynth Res* 70: 85-106.

Méjean, A. , Mann, S. , Maldiney, T. , Vassiliadis, G. , Lequin, O. , and Ploux, O. (2009) Evidence that biosynthesis of the neurotoxic alkaloids anatoxin-a and homoanatoxin-a in the cyanobacterium *Oscillatoria* PCC 6506 occurs on a modular polyketide synthase initiated by L-proline. *J Am Chem Soc* 131: 7512-7513.

Méjean, A. , Mann, S. , Vassiliadis, G. , Lombard, B. , Loew, D. , and Ploux, O. (2010a) In vitro reconstitution of the first steps of anatoxin-a biosynthesis in *Oscillatoria* PCC 6506: From free L-proline to acyl carrier protein bound dehydropyridine. *Biochemistry* 49: 103-113.

Méjean, A. , Mazmouz, R. , Mann, S. , Calteau, A. , Médigue, C. , and Ploux, O. (2010b) The genome sequence of the cyanobacterium *Oscillatoria* sp. PCC 6506 reveals several gene clusters responsible for the biosynthesis of toxins and secondary metabolites. *J Bacteriol* 192: 5264-5265. doi: <https://doi.org/10.1128/JB.00704-10>.

Meyer, F. , Goesmann, A. , McHardy, A.C. , Bartels, D. , Bekel, T. , Clausen, J. , Kalinowski, J. , Linke, B. , Rupp, O. , and Giegerich, R. (2003) GenDB-an open source genome annotation system for prokaryote genomes. *Nucleic Acids Res* 31: 2187-2195.

Michel, B. (2005) After 30 years of study, the bacterial SOS response still surprises us. *PLoS Biol* 3: e255. doi:https://doi.org/10.1371/journal.pbio.0030255

Mihali, T. K. , Kellmann, R. , Muenchhoff, J. , Barrow, K. D. , and Neilan, B. A. (2008) Characterization of the gene cluster responsible for cylindrospermopsin biosynthesis. *Appl Environ Microbiol* 74: 716-722.

Miller, S. R. , Augustine, S. , Olson, T. L. , Blankenship, R. E. , Selker, J. , and Wood, A. M. (2005) Discovery of a free-living chlorophyll d-producing cyanobacterium with a hybrid proteobacterial/cyanobacterial small-subunit rRNA gene. *Proc Natl Acad Sci USA* 102: 850-855.

Miyashita, H. , Adachi, K. , Kurano, N. , Ikemoto, H. , Chihara, M. , and Miyachi, S. (1997) Pigment composition of a novel oxygenic photosynthetic prokaryote containing chlorophyll d as the major chlorophyll. *Plant Cell Physiol* 38: 274-281.

Miyashita, H. , Adachi, K. , Kurano, N. , Ikemoto, H. , Chihara, M. , and Miyachi, S. (2003) *Acaryochloris marina* Gen. et Sp. nov. (Cyanobacteria), an oxygenic photosynthetic prokaryote containing Chl d as a major pigment. *J Phycol* 39: 1247-1253.

Miyashita, H. , Ikemoto, H. , Kurano, N. , Adachi, K. , Chihara, M. , and Miyachi, S. (1996) Chlorophyll d as a major pigment. *Nature (London)* 383: 402.

Mulkidjanian, A. Y. , Koonin, E. V. , Makarova, K. S. , Mekhedov, S. L. , Sorokin, A. , Wolf, Y. I. , Dufresne, A. , Partensky, F. , Burd, H. , Kanadzey, D. , Haselkorn, R. , and Galperin, M. Y. (2006) The cyanobacterial genome core and the origin of photosynthesis. *Proc Natl Acad Sci USA* 103: 13126-13131. doi: https://doi.org/10.1073/pnas.065709103

Murakami, A. , Miyashita, H. , Iseki, M. , Adachi, K. , and Mimuro, M. (2004) Chlorophyll d in an epiphytic cyanobacterium of red algae. *Science* 303: 1633.

Murata, N. , and Wada, H. (1995) Acyl-lipid desaturases and their importance in the tolerance and acclimatization to cold of cyanobacteria. *Biochem J* 308: 1-8.

Nakamura, T. , Naito, K. , Yokota, N. , Sugita, C. , and Sugita, M. (2007) A cyanobacterial non-coding RNA, Yfr1, is required for growth under multiple stress conditions. *Plant Cell Physiol* 48: 1309-1318.

Nakamura, Y. , Kaneko, T. , and Tabata, S. (2000) CyanoBase, the genome database for *Synechocystis* sp. PCC 6803: Status for the year 2000. *Nucleic Acids Res* 28: 72.

Nakamura, Y. , Kaneko, T. , Sato, S. , Ikeuchi, M. , Katoh, H. , Sasamoto, S. , Watanabe, A. , Iriguchi, M. , Kawashima, K. , Kimura, T. , Yishida, Y. , Kiyokawa, M. , Matsumoto, M. , Matsuno, A. , Nakazaki, N. , Shimpo, S. , Sugimoto, M. , Takeuchi, C. , Yamada, M. , and Tabata, S. (2002) Complete genome structure of the thermophilic cyanobacterium *Thermosynechococcus elongatus* BP-1. *DNA Res* 9: 123-130.

Nakamura, Y. , Kaneko, T. , Sato, S. , Minuro, M. , Miyashita, H. , Tsuchiya, T. , Sasamoto, S. , Watanabe, A. , Kawashima, K. , Kishida, Y. , Kiyokawa, C. , Kohara, M. , Matsumoto, M. , Matsuno, A. , Nakazaki, N. , Shimpo, S. , Takeuchi, C. , Yamada, M. , and Tabata, S. (2003) Complete genome structure of *Gloeobacter violaceus* PCC 7421, a cyanobacterium that lacks thylakoids. *DNA Res* 10: 137-145.

Neuwald, A. F. , Liu, J. S. , Lipman, D. J. , and Lawrence, C. E. (1997) Extracting protein alignment models from the sequence database. *Nucleic Acids Res* 25: 1665-1677.

Ochoa de Alda, J. A. G. , and Houmard, J. (2000) Genomic survey of cAMP and cGMP signaling components in the cyanobacterium *Synechocystis* PCC 6803. *Microbiology* 146: 3183-3194.

Ochoa de Alda, J. A. G. , Ajlani, G. , and Houmard, J. (2000). The *Synechocystis* PCC 6803 *cya2*, a prokaryotic gene that encodes a guanylyl cyclase. *J Bacteriol* 182: 3839-3842.

Ohkubo, S. , Miyashita, H. , Murakami, A. , Takeyama, H. , Tsuchiya, T. , and Mimuro, M. (2006). Molecular detection of epiphytic *Acaryochloris* spp. on marine macroalgae. *Appl Environ Microbiol* 72: 7912-7915.

Oliveira, P. , and Lindblad, P. (2005) LexA, a transcription regulator binding in the promoter region of the bidirectional hydrogenase in the cyanobacterium *Synechocystis* sp. PCC 6803. *FEMS Microbiol Lett* 251: 59-66.

Olmstead, R. G. , and Palmer, J. D. (1994) Chloroplast DNA systematics: A review of methods and data analysis. *Am J Bot* 81: 1205-1224.

Overbeek, R. , Fonstein, M. , D'Souza, M. , Pusch, G. D. , and Maltsev, N. (1999) The use of gene clusters to infer functional coupling. *Proc Natl Acad Sci USA* 96: 2896-2901.

Palenik, B. , Brahamsha, B. , Larimer, F. W. , Land, M. , Hauser, L. , Chain, P. , Lamerdin, J. , Regala, W. , Allen, E. E. , NcCarren, J. , Paulsen, I. , Dufresne, A. , Pratsensky, F. , Webb, E. G. , and Waterbury, J. (2003) The genome of a motile marine *Synechococcus*. *Nature (London)* 424: 1037-1042.

Palenik, B. , Ren, Q. , Dupont, C. L. , Myers, G. S. , Heidelberg, J. F. , Badger, J. H. , Madupu, R. , Nelson, W. L. , Brinkac, L. M. , Dadson, R. L. , Durkin, A. S. , Daugherty, S. C. , Sullivan, S. A. , Khouri, H. , Mohamoud, Y. , Halpin, R. , and Paulsen, I. T. (2006) Genome sequence of *Synechococcus* CC9311: Insights into adaptation to a coastal environment. *Proc Natl Acad Sci USA* 103: 13555-13559.

Patterson-Fortin, L. M. , and Owtrim, G. W. (2008) A *Synechocystis* LexA-orthologue binds direct repeats in target genes. *FEBS Lett* 582: 2424-2430.

Ran, L. , Larsson, J. , Vigil-Stenman, T. , Nylander, J. A. A. , Ininbergs, K. , Zheng, W-W. , Lapidus, A. , Lowry, S. , Haselkorn, R. , and Berman, B. (2010) Genome erosion in a nitrogen-fixing vertically transmitted endosymbiotic multicellular cyanobacterium. *PLoS ONE* 5: e11486. doi:https://doi.org/10.1371/journal.pone.0011486

Raubeson, L. A. , and Jansen, R. K. (1992) Chloroplast DNA: Evidence on the ancient evolutionary split in vascular land plants. *Science* 255: 1697-1699.

Reitzer, L. (2003) Nitrogen assimilation and global regulation in *Escherichia coli*. *Annu Rev Microbiol* 57: 155-176.

Riley, M. (1993) Functions of the gene products of *Escherichia coli*. *Microbiol Rev* 57: 862-952.

Rocap, G. , Larimer, F. W. , Lamerdin, J. , Malfatti, S. , Chain, P. , Ahlgren, N. A. , Arellano, A. , Coleman, M. , Hauser, L. , Hess, W. R. , Johnson, Z. I. , Land, M. , Lindell, D. , Post, A. F. , Regala, W. , Shal, M. , Shaw, S. L. , Steglich, C. , Sullivan, M. B. , Ting, C. S. , Tolonen, A. , Webb, E. A. , Zinser, E. R. , and Chisholm, S. W. (2003) Genome divergence in two *Prochlorococcus* ecotypes reflects oceanic niche differentiation. *Nature (London)* 424: 1042-1047.

Sabatti, C. , Rohlin, L. , Oh, M. K. , and Liao, J. C. (2002) Co-expression pattern from DNA microarray experiments as a tool for operon prediction. *Nucleic Acids Res* 30: 2886-2893.

Salgado, H. , Moreno-Hagelsieb, G. , Smith, T. F. , Collado-Vides, J. (2000) Operons in *Escherichia coli*: Genomic analyses and predictions. *Proc Natl Acad Sci USA* 97: 6652-6657.

Salzberg, S. L. , Delcher, A. L. , Kasif, S. , and White, O. (1998) Microbial gene identification using interpolated Markov models. *Nucleic Acids Res* 26: 544-548.

Sato, N. (2003) Gclust: Genome-wide clustering of protein sequences for identification of photosynthesis-related genes resulting from massive horizontal gene transfer. *Genome Informatics* 14: 585-586.

Satoh, S., and Tanaka, A. (2006) Identification of chlorophyllide a oxygenase in the *Prochlorococcus* genome by a comparative genome approach. *Plant Cell Physiol* 47: 1622-1629. doi:<https://doi.org/10.1093/pcp/pcl026>

Scharf, M., Schneider, R., Casari, G., Bork, P., Valencia, A., Ouzounis, C., and Sander, C. (1994) GeneQuiz: A workbench for sequence analysis. *Ismb* 2: 348-353.

Scheller, H. V., Jensen, P. E., Haldrup, A., Lunde, C., and Knoetzel, J. (2001) Role of subunits in eukaryotic photosystem I. *Biochim Biophys Acta* 1507: 41-60.

Shi, T., and Falkowski, P. G. (2008) Genome evolution in cyanobacteria: The stable core and the variable shell. *Proc Natl Acad Sci USA* 105: 2510-2515.

Six, C., Thomas, J.-C., Garczarek, L., Ostrowski, M., Dufresne, A., Blot, N., Scanlan, D. J., and Partensky, F. (2007) Diversity and evolution of phycobilisomes in marine *Synechococcus* sp.: A comparative genomics study. *Genome Biol* 8: R259s. doi:<https://doi.org/10.1186/gb-2007-8-12-r259>

Sjöholm, J., Oliveira, P., and Lindblad, P. (2007) Transcription and regulation of the bidirectional hydrogenase in the cyanobacterium *Nostoc* sp. strain PCC 7120. *Appl Environ Microbiol* 73: 5435-5446.

Stork, T., Michel, K.-P., Pistorius, E. K., and Dietz, K.-J. (2005) Bioinformatic analysis of the genomes of the cyanobacteria *Synechocystis* sp. PCC 6803 and *Synechococcus elongatus* PCC 7942 for the presence of peroxiredoxins and their transcription regulation under stress. *J Exp Bot* 56: 3193-3206. doi:<https://doi.org/10.1093/jxb/eri316>

Steglich, C., Futschik, M. E., Lindell, D., Voss, B., Chisholm, S. W., and Hess, W. R. (2008) The challenge of regulation in a minimal photoautotroph: Non-coding RNAs in *Prochlorococcus*. *PLoS Genet* 4: e1000173. doi:10.1371/journal.pgen.1000173

Stroebel, D., Choquet, Y., Popot, J. L., and Picot, D. (2003) An atypical haem in the cytochrome b(6)f complex. *Nature (London)* 426: 413-418.

Stubbs, C. D., and Smith, A. D. (1984) The modification of mammalian membrane polyunsaturated fatty acid composition in relation to membrane fluidity and function. *Biochim Biophys Acta* 779: 89-137.

Stucken, K., John, U., Cembella, A., Murillo, A. A., Soto-Liebe, K., Fuentes-Valdés, J. J., Friedel, M., Plominsky, A. M., Vásquez, M., and Glöckner, G. (2010) The smallest known genomes of multicellular toxic cyanobacteria: Comparison of minimal gene sets for linked traits and the evolutionary implications. *PLoS ONE* 5: e9235. doi: <https://doi.org/10.1371/journal.pone.0009235>

Su, Z., Olman, V., Mao, F., and Xu, Y. (2005) Comparative genomics analysis of *ntcA* regulons in cyanobacteria: Regulation of nitrogen assimilation and its coupling to photosynthesis. *Nucleic Acids Res* 33: 5156-5171. doi:<https://doi.org/10.1093/nar/gki817>

Su, Z., Olman, V., and Xu, Y. (2007) Computational prediction of Pho regulons in cyanobacteria. *BMC Genomics* 8: 156. doi: <https://doi.org/10.1186/1471-2164-8-156>

Sugaya, N., Murakami, H., Satoh, M., Aburatani, S., and Horimoto, K. (2003) Gene distribution patterns on cyanobacterial genomes. *Genome Informatics* 14: 561-562.

Sugaya, N., Sato, M., Murakami, H., Imaizumi, A., Aburatani, S., and Horimoto, K. (2004) Causes for the large genome size in a cyanobacterium *Anabaena* sp. PCC 7120. *Genome Informatics* 15: 229-238.

Sugita, C., Ogata, K., Shikata, M., Jikuya, H., Takano, J., Furlimichi, M., Kanchisa, M., Omata, T., Sugiura, M., and Sugita, M. (2006) Complete nucleotide sequence of the freshwater unicellular cyanobacterium *Synechococcus elongatus* PCC 6301 chromosome: Gene content and organization. *Photosynth Res* doi:<https://doi.org/10.1007/s11120-006-9122-4>

Suzuki, S., Ferjani, A., Suzuki, I., and Murata, N. (2004) The SphS-SphR two-component system is the exclusive sensor for the induction of gene expression in response to phosphate limitation in *Synechocystis*. *J Biol Chem* 279: 13234-13240.

Swingle, W.D., Chen, C., Chuang, P. C., Conrad, A. L., Dejesa, L. C., Hao, J., Honchak, B. M., Karbach, L. E., Kurdoglu, A., Lahiri, S., Mastrain, S. D., Miyashita, H., Page, L., Ramakrishna, P., Satoh, S., Sattley, W.M., Shimada, Y., Taylor, H. L., Tomo, T., Tsuchiya, T., Wang, W. T., Raymond, J., Mimuro, M., Blankenship, R. E., and Touchman, J. W. (2008) Niche adaptation and genome expansion in the chlorophyll d-producing cyanobacterium *Acaryochloris marina*. *Proc Natl Acad Sci USA* 105: 2005-2010. doi:<https://doi.org/10.1073/pnas.0709772105>

Tatusov, R. L., Koonin, E. V., and Lipman, D. J. (1997) A genomic perspective on protein families. *Science* 278: 631-637.

Tatusov, R. L., Galperin, M. Y., Natale, D. A., and Koonin, E. V. (2000) The COG database: A tool for genome-scale analysis of protein functions and evolution. *Nucleic Acids Res* 28: 33-36.

Tatusov, R. L., Natale, D. A., Garkavtsev, I. V., Tatusova, T. A., Shankavaram, V. T., Rao, B. S., Kiryutin, B., Galperin, M. Y., Fedorova, N. D., and Koonin, E. V. (2001) The COG database: new developments in phylogenetic classification of proteins from complete genomes. *Nucleic Acids Res* 29: 22-28.

Tatusov, R. L., Fedorova, N. D., Jackson, J. D., Jacobs, A. R., Kiryutin, B., Koonin, E. V., Krylov, D. M., Mazumder, R., Mekhedov, S. L., Nikolskaya, A. N., Rao, B. S., Smirnov, S., Sverdlov, A. V., Vasudevan, S., Wolf, Y. I., Yin, J. J., and Natale, D. A. (2003) The COG database: an updated version includes eukaryotes. *BMC Bioinformatics* 4: 41. doi:<https://doi.org/10.1186/1471-2105-4-41>

Terauchi, K., and Ohmori, M. (1999) An adenylate cyclase, Cya1, regulates cell motility in the cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 40: 248-251.

Umena, Y., Kawakami, K., Shen, J.-R., and Kamiya, N. (2011) Crystal structure of oxygen-evolving photosystem II at a resolution of 1.9 angstrom. *Nature (London)* 473: 55-60. doi: <https://doi.org/10.1038/nature09913>

Urbach, E., Scanlan, D. J., Distel, D. L., Waterbury, J.B., and Chisholm, S. W. (1998) Rapid diversification of marine picophytoplankton with dissimilar light-harvesting structures inferred from sequences of *Prochlorococcus* and *Synechococcus* (Cyanobacteria). *J Mol Evol* 46: 188-201.

Vallenet, D., Labarre, L., Rouy, Z., Barbe, V., Bocs, S., Cruveiller, S., Lajus, A., Pascal, G., Scarpelli, C., and Medigue, C. (2006) MaGe: A microbial genome annotation system supported by synteny results. *Nucleic Acids Res* 34: 53-65.

Veal, E. A., Findlay, V. J., Day, A. M., Bozonet, S. M., Evans, J. M., Quinn, J., Morgan, B. A. (2004) A 2-Cys peroxiredoxin regulates peroxide-induced oxidation and activation of a stress-activated MAP kinase. *Mol Cell* 15: 129-139.

Wang, L.-S., Warnow, T., Moret, B., Jansen, R., and Raubeson, L. (2006) Distance-based genome rearrangement phylogeny. *J Mol Evol* 63: 473-483.

Ward, D. M., Cohan, F. M., Bhaya, D., Heidelberg, J. F., Kühl, M., and Grossman, A., (2008) Genomics, environmental genomics and the issue of microbial species. *Heredity* 100: 207-219. doi:<https://doi.org/10.1038/sj.hdy.6801011>

Waterbury, J.B. and Rippka, R. (1989) Order Chroococcales Wettstein 1924, emend. Rippka et al. 1979. In: Staley, J. T. , Bryant, M. P. , Pfennig, N. , and Holt, J. G. . (Eds.), *Bergey's Manual of Systematic Bacteriology*, vol. 3. Williams & Wilkins, Baltimore, USA pp. 1728-1746.

Welsh, E. A. , Liberton, M. , Stöckel, J. , Loh, T. , Elvitigalo, T. , Wang, C. , Wollman, A. , Fulton, R. S. , Clifton, S. W. , Jacobs, J. M. , Aurora, R. , Ghosh, B. K. , Sherman, L. A. , Smith, R. D. , Wilson, R. K. , and Pakrasi, H. B. (2008) The genome of *Cyanothece* 51142, a unicellular diazotrophic cyanobacterium important in the marine nitrogen cycle. *Proc Natl Acad Sci USA* 105: 15094-15099. doi:1073/pnas.0805418105

Wood, Z. A. , Poole, L. B. , and Karplus, P. A. (2003a) Peroxiredoxin evolution and the regulation of hydrogen peroxide signaling. *Science* 300: 650-653.

Wood, Z. A. , Schroder, E. , Robin Harris, J. , and Poole, L. B. (2003b) Structure, mechanism and regulation of peroxiredoxins. *Trends Biochem Sci* 28: 32-40.

Wu, J. , Zhao, F. , Wang, S. , Deng, G. , Wang, J. , Bai, J. , Lu, J. , Qu, J. , and Bao, Q. (2007) cTF: A database for comparative genomics for transcription factors in cyanobacteria. *BMC Genomics* 8: 104. doi:https://doi.org/10.1186/1471-2164-8-104.

Xu, M. , and Su, Z. (2009) Computational prediction of cAMP receptor (CRP) binding sites in cyanobacterial genomes. *BMC Genomics* 10: 23. doi:https://doi.org/10.1186/1471-2164-10-23

Yang, Y. , Qin, S. , Zhao, F. , Chi, X. , and Zhang, X. (2007) Comparison of envelope-related genes in unicellular and filamentous cyanobacteria. *Comp Funct Genomics* 2007. doi:https://doi.org/10.1155/2007/25751

Zhang, X. , Zhao, F. , Guan, X. , Yang, Y. , Liang, C. , and Qin, S. (2007) Genome-wide survey of putative serine/threonine protein kinases in cyanobacteria. *BMC Genomics* 8: 395. doi:https://doi.org/10.1186/1471-2164-8-395

Zheng, Y. , Szustakowski, J. D. , Fortnow, L. , Roberts, R. J. , and Kasif, S. (2002) Computational identification of operons in microbial genomes. *Genome Res* 12: 1221-1230.

Zuker, M. (2003) Mfold web server for nucleic acid folding and hybridization prediction. *Nucleic Acids Res* 31: 3406-3415.

Akinetes

Adams, D. G. , and Carr, N. G. (1981) The developmental biology of heterocyst and akinete formation in cyanobacteria. *Crit Rev Microbiol* 9: 45-100.

Adams, D. G. , and Duggan, P. S. (1999) Heterocyst and akinete differentiation in cyanobacteria. *New Phytol* 144: 1-33.

Agrawal, S. C. , and Singh, V. (2000) Vegetative survival, akinete formation and germination in three blue-green algae and one green alga in relation to light intensity, temperature, heat shock and UV exposure. *Folia Microbiol* 45: 439-446.

Ahluwalia, A. S. , and Kumar, H. D. (1982) Cellular differentiation and nitrogenase activity in the cyanobacterium *Anabaena*. *Beitr Biol Pflanzen* 57: 459-467.

Ahluwalia, A. S. , and Kumar, H. D. (1983) Pattern of akinete differentiation in the blue-green alga *Nostoc* sp. *Beitr Biol Pflanzen* 57: 459-467.

Ahuja, G. , Khattar, J. I. S. , and Sarma, T. A. (2008) Interaction between carbon and nitrogen metabolism during akinete development in the cyanobacterium *Anabaena torulosa*. *J Basic Microbiol* 48: 125-129.

Argueta, C. , and Summers, M. L. (2005) Characterization of a model system for the study of *Nostoc punctiforme* akinetes. *Arch Microbiol* 183: 338-346.

Argueta, C. , Yuksek, K. , and Summers, M. L. (2004) Construction and use of GFP reporter vectors for analysis of cell-type-specific gene expression in *Nostoc punctiforme*. *J Microbiol Methods* 59: 181-188.

Argueta, C. , Yuksek, K. , Patel, R. , and Summers, M. L. (2006) Identification of *Nostoc punctiforme* akinete-expressed genes using differential display. *Mol Microbiol* 61: 748-757.

Baker, P. D. (1999) Role of akinetes in the development of cyanobacterial populations in the lower Murray River, Australia. *Mar Freshwater Res* 50: 265-279.

Baker, P. D. , and Bellifemine, D. (2000) Environmental influences on akinete germination of *Anabaena circinalis* and implications for management of cyanobacterial blooms. *Hydrobiologia* 427: 65-73.

Braune, W. (1979) C-phycocyanin—the main photoreceptor in the light-dependent germination process of *Anabaena* akinetes. *Arch Microbiol* 122: 289-295.

Braune, W. (1980) Structural aspects of akinete germination in the cyanobacterium *Anabaena variabilis*. *Arch Microbiol* 126: 257-261.

Burger, J. (1974) A study of two populations of *Anabaena planctonica* Brunnth. (Cyanophyta) from Minnesota. *Phycologia* 13: 125-129.

Campbell, E. L. , Hagen, K. D. , Cohen, M. F. , Summers, M. L. , and Meeks, J. C. (1996) The devR gene product is characteristic of receivers of two-component regulatory systems and is essential for heterocyst development in the filamentous cyanobacterium *Nostoc* sp. strain ATCC 29133. *J Bacteriol* 178: 2037-2043.

Campbell, E. L. , Summers, M. L. , Christman, H. , Martin, M. E. , and Meeks, J. C. (2007) Global gene expression patterns of *N. punctiforme* in steady state dinitrogen grown heterocyst-containing cultures and at single time points during the differentiation of akinetes and hormogonia. *J Bacteriol* 189: 5247-5256.

Canabaeus, L. (1929) Über die Heterocysten und Gasvakuolen der Blaualgen und ihre Beziehung zueinander. *Pflanzenforschung* 13: 1-48.

Cardemil, L. , and Wolk, C. P. (1976) The polysaccharides from heterocysts and spore envelopes of a blue-green alga. *J Biol Chem* 251: 2967-2975.

Cardemil, L. , and Wolk, C. P. (1979) The polysaccharides from heterocysts and spore envelopes of a blue-green alga. Structure of basic repeating subunit. *J Biol Chem* 254: 736-741.

Cardemil, L. , and Wolk, C. P. (1981) Polysaccharides from the envelopes of heterocysts and spores of the blue-green algae *Anabaena variabilis* and *Cylindrospermum licheniforme*. *J Phycol* 17: 234-240.

Carter, H. J. (1856) Notes on the freshwater infusoria of the island of Bombay. No. 1. Organisation. *Ann Magazine Natural Hist* 18: 115-132, 221-249.

Chauvat, F. , Corre, B. , Herdman, M. , and Joset-Espardellier, F. (1981) A freezing method for the purification and storage of akinete suspensions of the cyanobacterium *Nostoc* PCC 7524. *FEMS Microbiol Lett* 10: 319-321.

Chauvat, F. , Corre, B. , Herdman, M. , and Joset-Espardellier, F. (1982) Energetic and metabolic requirements for the germination of akinetes of the cyanobacterium *Nostoc* PCC 7524. *Arch Microbiol* 133: 44-49.

Cheung, W. Y. , and Gibbs, M. (1965) Dark and photometabolism of sugars by a blue-green alga *Tolypothrix tenuis*. *Plant Physiol* 41: 451-462.

Cmiech, H. A. , Reynolds, C. S. , and Leedale, G. F. (1984) Seasonal periodicity, heterocyst differentiation and sporulation of planktonic cyanophyceae in a shallow lake, with special reference to *Anabaena solitaria*. *Eur J Phycol* 19: 245-257.

Dhar, B. (1979) Nutritional control of frequency of MNNG induced true branching habit in *Anabaena doliolum*. *Mol Gen Genet* 173: 171-181.

Dikshit, K. L. , Dikshit, R. P. , and Verma, S. C. (1981) Induction of oligosporogenous mutants of a blue-green alga *Anabaena doliolum* by acriflavine and acridine orange. *Ann Bot* 48: 235-242.

Doolittle, W.F. , and Singer, R.A. , (1974) Mutational analysis of dark endogenous metabolism in the blue-green bacterium *Anacystis nidulans*. *J Bacteriol* 119: 677-683.

Doughty, D. M. , Hunter, R. C. , Summons, R. E. , and Newman, D. K. (2009) 2-Methylhopanoids are maximally produced in akinetes of *Nostoc punctiforme*: Geobiological implications. *Geobiology* 7: 524-532.

Dunn, J. H. , and Wolk, C. P. (1970) Composition of cellular envelopes of *Anabaena cylindrica*. *J Bacteriol* 103: 153-158.

Eberly, W. R. (1966) Notes on some new and rare Myxophyceae in laboratory culture. *Trans Am Microscop Soc* 85: 130-138.

Fay, P. (1969a) Cell differentiation and pigment composition in *Anabaena cylindrica*. *Arch Microbiol* 67: 62-70.

Fay, P. (1969b) Metabolic activities of isolated spores of *Anabaena cylindrica*. *J Exp Bot* 20: 100-109.

Fay, P. (1988) Viability of akinetes of the planktonic cyanobacterium *Anabaena circinalis*. *Proc R Soc B London* 234: 283-301.

Fay, P. , Lynn, J. A. , and Majer, S. C. (1984) Akinete development in the planktonic blue- green alga *Anabaena circinalis*. *British Phycol J* 19: 163-173.

Fernandes, T. A. , and Thomas, J. (1982) Control of sporulation in the filamentous cyanobacterium *Anabaena torulosa*. *J Biosci* 4: 85-94.

Fisher, R. W. , and Wolk, C. P. (1976) Substance stimulating the differentiation of spores of the blue-green alga, *Cylindrospermum licheniforme*. *Nature (London)* 259: 394-395.

Fogg, G. E. , Stewart, W. D. P. , Fay, P. , and Walsby, A. E. (1973) *The Blue-green Algae*. Academic Press, London. pp. 459.

Forchhammer, K. , and Tandeau de Marsac, N. (1994) The PII protein in the cyanobacterium *Synechococcus* sp. strain PCC 7942 is modified by serine phosphorylation and signals the cellular N-status. *J Bacteriol* 176: 84-91.

Fritsch, F. E. (1945) *The Structure and Reproduction of the Algae*, Vol. II, Cambridge University Press, Cambridge, England, UK pp. 796.

Giesy, R. M. (1964) A light and electron microscope study of intralamellar polyglucoside bodies in *Oscillatoria chalybea*. *Am J Bot* 51: 388-396.

Golubic, S. , Sergeev, V. N. , and Knoll, A. H. (1995) Mesoproterozoic Archaeoellipsoides: Akinetes of heterocystous cyanobacteria. *Lethaia* 28: 285-298.

Grilli-Caiola, M. , and de-Vecchi, L. (1980) Akinete ultrastructure of *Nostoc* species isolated from cycad coralloid roots. *Can J Bot* 58: 2513-2519.

Hadas, O. , Pinkas, R. , Delphine, E. , Vardi, A. , Kaplan, A. and Sukenik, A. (1999) Limnological and ecophysiological aspects of *Aphanizomenon ovalisporum* bloom in Lake Kinneret, Israel. *J. Plankton Res* 21: 1439-1453.

Haselkorn, R. (1978) Heterocysts. *Annu Rev Plant Physiol* 29: 319-344.

Head, R. M. , Jones, R. I. , and Bailey-Watts, A. E. (1998) Akinete germination and recruitment of planktonic cyanobacteria from lake sediments. *Verh Int Ver Limnol* 26: 1711-1715.

Head, R. M. , Jones, R. I. and Bailey-Watts, A. E. (1999) An assessment of the influence of recruitment from the sediment on the development of planktonic populations of cyanobacteria in a temperate mesotrophic lake. *Freshwater Biol* 41: 759-769.

Herdman, M. (1987) Akinetes: Structure and function. In: Fay, P. , and Van Baalen, C. (Eds.) *The Cyanobacteria*. Elsevier, Amsterdam, The Netherlands pp. 227-250.

Herdman, M. (1988) Cellular differentiation: Akinetes. *Methods Enzymol* 167: 222-232.

Hill, H. (1970) A new form of *Raphidiopsis mediterranea* Skuja found in Minnesota lake. *Phycologia* 9: 73-77.

Hirosawa, T. , and Wolk, C. P. (1979a) Factors controlling the formation of akinetes adjacent to heterocysts in the cyanobacterium, *Cylindrospermum licheniforme* Kuetz. *J Gen Microbiol* 114: 423-432.

Hirosawa, T. , and Wolk, C. P. (1979b) Isolation and characterization of a substance which stimulates the formation of akinetes in the cyanobacterium *Cylindrospermum licheniforme* Kuetz. *J Gen Microbiol* 114: 433-441.

Hori, K. , Okamoto, J. , Tanji, Y. , and Unno, H. (2003) Formation, sedimentation and germination properties of *Anabaena* akinetes. *Biochem Eng J* 14: 67-73.

Huber, A. L. (1984) *Nodularia* (Cyanobacteriaceae) akinetes in the sediments of the Peel-Harvey estuary western Australia: Potential inoculum source for *Nodularia* blooms. *Appl Environ Microbiol* 47: 234-238.

Huber, A. L. (1985) Factors affecting germination of akinetes of *Nodularia spumigena* (Cyanobacteriaceae). *Appl Environ Microbiol* 49: 73-78.

Jensen, T. E. , and Clark, R. L. (1969) Cell wall and coat of the developing akinete of a *Cylindrospermum* species. *J Bacteriol* 97: 1494-1495.

Karlsson-Elfgren, I. , Rengefors, K. , and Gustafsson, S. (2004) Factors regulating recruitment from the sediment to the water column in the bloom-forming cyanobacterium *Gloeotrichia echinulata*. *Freshwater Biol* 49: 265-273.

Kaushik, M. , and Kumar, H. D. (1970) The effects of light on growth and development of two nitrogen fixing blue-green algae. *Arch Microbiol* 79: 52-57.

Kaushik, M. , Kumar, H. D. , and Singh, H. N. (1971) Studies on growth and development of two nitrogen fixing blue-green algae. I. Carbon and phosphorus nutrition. *Z Pflanzenphysiol* 65: 432-442.

Keck, K. , and Stich, H. (1957) The wide spread occurrence of polyphosphate in lower plants. *Ann Bot* 21: 611-619.

Kim, B. H. , Lee, W. S. , Kim, Y.-O. , Lee, H.-O. , and Han, M.-S. (2005) Relationship between akinete germination and vegetative population of *Anabaena flos-aquae* (Nostocales, Cyanobacteria) in Seokchon reservoir (Seoul, Korea). *Arch Hydrobiol* 163: 49-64.

Kravchuk, E. S. , Ivanova, E. A. , and Glayshev, M. I. (2002) Seasonal dynamics of the numbers of *Anabaena flos-aquae* (Lyngb.) Breb. akinetes in the surface layer of bottom sediments and bulk water. *Doklady Biol Sci* 384: 233-234.

Kravchuk, E. S. , Ivanova, E. A. , and Gladyshev, M. I. (2011) Spatial distribution of resting stages (akinetes) of the cyanobacteria *Anabaena flos-aquae* in sediments and its influence in pelagic populations. *Mar Freshwater Res* 62: 450-461. doi:10.1071/MF10256.

Lang, N. J. (1967) The fine structure of blue-green algae. *Annu Rev Microbiol* 22: 15-46.

Leak, L. V. , and Wilson, G. B. (1965) Electron microscopic observations on a blue-green alga, *Anabaena* sp. *Can J Genet Cytol* 7: 237-249.

Leganés, F. , Fernandez-Piñás, F. , and Wolk, C. P. (1994) Two mutations that block heterocyst differentiation have no effect on akinete differentiation in *Nostoc ellipsosporum*. *Mol Microbiol* 12: 679-684.

Leganés, F. , Fernandez-Piñás, F. , and Wolk, C. P. (1998) A transposition-induced mutant of *Nostoc ellipsosporum* implicates an arginine-biosynthetic gene in the formation of cyanophycin granules and of functional heterocysts and akinetes. *Microbiology* 144: 1799-1805.

Li, R. , Watanabe, M. , and Watanabe, M. M. (1997) Akinete formation in planktonic *Anabaena* spp. (Cyanobacteria) by the treatment with low temperature. *J Phycol* 33: 576-584.

Livingstone, D. , and Jaworski, G. H. M. (1980) The viability of akinetes of blue-green algae recovered from the sediments of Rostherne Mere. *Br Phycol J* 15: 357-364.

Miller, M. M. , and Lang, N. J. (1968) The fine structure of akinete formation and germination in *Cylindrospermum*. *Arch Microbiol* 60: 303-313.

Meeks, J. C. , Campbell, E.L. , Summers, M.L. , and Wong, F. C. (2002) Cellular differentiation in the cyanobacterium *Nostoc punctiforme*. *Arch Microbiol* 178: 395-403.

Miller, M. M. , and Lang, N. J. (1968) The fine structure of akinete formation and germination in *Cylindrospermum*. *Arch Microbiol* 60: 303-313.

Moore, D. , McGregor, G. B. , and Shaw, G. (2004) Morphological changes during akinete germination in *Cylindrospermopsis raciborskii* (Nostocales, Cyanobacteria). *J Phycol* 40: 1098-1105.

Moore, D. , O'Donohue, M. , Garnett, C. M. , Shaw, G. R. , and Critchley, C. (2005) Factors affecting akinete differentiation in *Cylindrospermopsis raciborskii*. *Freshwater Biol* 50: 345-352.

Myers, J. M. , Beardall, J. , Allinson, G. , Salzman, S. , and Gunthorpe, L. (2010) Environmental influences on akinete germination and development in *Nodularia spumigena* (Cyanobacteriaceae) isolated from Gippsland lakes, Victoria, Australia. *Hydrobiologia* 649: 239-247.

Neely-Fisher, D. L. , Bruce White, W. , and Fisher, R. W. (1989) Fructose-induced dark germination of *Anabaena* akinetes. *Curr Microbiol* 19: 139-142.

Neur, G. , Papen, H. , and Bothe, H. (1983) Heterocyst biochemistry and differentiation. In: Papargeorgiou, G. C. , and Packer, L. (Eds.) *Photosynthetic Prokaryotes: Cell Differentiation and function* Elsevier, New York, NY, USA. pp. 219-242.

Nichols, J. M. , and Adams, D. G. (1982) Akinetes. In: Carr, N. G. , and Whitton, B. A. (Eds.) *The Biology of Cyanobacteria*. Blackwell Scientific Publications, Oxford, UK pp. 387-412.

Nichols, J. M. , and Carr, N. G. (1978) Akinetes of cyanobacteria. In: Chambers, G. , and Vary, J. M. (Eds.) *Spores Am Soc Microbiologists*, Washington, pp. 335-343.

Nichols, J. M. , Adams, D. G. , and Carr, N. G. (1980) Effect of canavanine and other amino acid analogues on akinete formation in the cyanobacterium *Anabaena cylindrica*. *Arch Microbiol* 127: 67-75.

Olsson, , Francis, K. , de La Torre, R. , Towner, M. C. , and Cockell, C. S. (2009) Survival of akinetes (resting state cells of cyanobacteria) in low Earth orbit and simulated extraterrestrial conditions. *Origins of Life and Evolution of Biospheres* 39: 565-579.

Pandey, K. D. , and Kashyap, A. K. (1987) Factors affecting formation of spores (akinetes) in cyanobacterium *Anabaena doliolum* (Ads. Strain). *J Plant Physiol* 127: 123-134.

Pandey, R. K. , and Talpasayi, E. R. S. (1980) Control of sporulation in a blue-green alga, *Nodularia spumigena* Mertens. *Indian J Bot* 3: 128-133.

Pandey, R. K. , and Talpasayi, E. R. S. (1981) Physiological and biochemical aspects of formation and germination of spores in blue-green algae. In: Bharadwaj, D.C. (Ed.) *Recent Advances in Cryptogamic Botany*, Palaeobotanical Society, Lucknow. pp. 1-14.

Pankratz, H. S. , and Bowen, C. C. (1963) Cytology of blue-green algae. I. The cells of *Symploca mucorum*. *Am J Bot* 50: 387-399.

Pelroy, R. A. , and Bassham, J. A. (1972) Photosynthesis and dark carbon metabolism in unicellular blue-green algae. *Arch Microbiol* 86: 25-28.

Rai, A. K. , and Pandey, G. P. (1981) Influence of environmental stress on the germination of *Anabaena vaginicola* akinetes. *Ann Bot* 48: 361-370.

Rai, A. N. , Rao, V. V. , and Singh, H. N. (1985) The biology of the cyanobacterial (blue-green-algal) akinetes (spores). *J Plant Sci Res* 1: 1-20.

Rai, A. N. , Rao, V. V. , and Singh, H. N. (1988) Metabolic changes associated with akinete germination in the cyanobacterium *Anabaena doliolum*. *New Phytol* 109: 133-138.

Rao, V. V. , Ghosh, R. , and Singh, H. N. (1987) Diazotrophic regulation of akinete development in the cyanobacterium *Anabaena doliolum*. *New Phytol* 106: 161-168.

Rao, V. V. , Rai, A. N. , and Singh, H. N. (1984) Metabolic activities of akinetes of the cyanobacterium *Anabaena doliolum*: Oxygen exchange, photosynthetic pigments and enzymes of nitrogen metabolism. *J Gen Microbiol* 130: 1299-1302.

Reddy, P. M. (1976) Physiological and biochemical studies on cellular differentiation with special reference to perennating structures of blue-green algae. Ph. D. Thesis in Botany, Banaras Hindu University, Varanasi, India.

Reddy, P. M. , and Talpasayi, E. R. S. (1981) Some observations related to red-far red antagonism in germination of spores of the cyanobacterium *Anabaena fertilissima*. *Biochem Physiol Pflanzen* 176: 105-107.

Reddy, P. M. (1983a) Changes in phycobiliproteins during spores (akinetes) differentiation in a cyanobacterium *Anabaena fertilissima*. *Biochim Biophys Acta* 761: 191-195.

Reddy, P. M. (1983b) Effects of temperature pre-treatment on the viability of spores of halophilic blue-green algae. *Hydrobiologia* 106: 235-240.

Rippka, R. , Deruelles, J. , Waterbury, J. B. , Herdmann, M. , and Stanier, R. Y. (1979) Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *J Gen Microbiol* 111: 1-61.

Ris, H. , and Singh, R. N. (1961) Electron microscope studies on blue-green algae. *J Biophys Biochem Cytol* 9: 63-80.

Rother, J. A. , and Fay, P. (1977) Sporulation and the development of planktonic blue-green algae in two Salopian meres. *Proc R Soc B London* 196: 317-332.

Rother, J. A. , and Fay, P. (1979) Blue-green algal growth and sporulation in response to simulated surface bloom conditions. *Br Phycol J* 14: 59–68.

Sarma, T. A. (1993) Akinete differentiation in the cyanobacterium *Anabaena torulosa*. *Proc Natl Sem Cyanobacterial Research-Indian Scene*, NFMC, Bharathidasan University, Tirucirapally. pp. 50–62.

Sarma, T. A. , and Garg, R. (1985) Effect of carbonates and bicarbonates on the growth and sporulation in two blue-green algae. *Proc Indian Acad Sci (Plant Sci)* 94: 45–50.

Sarma, T. A. , and Ghai, R. (1998) Pattern of akinete differentiation in the cyanobacterium *Scytonema fritschii*. *Folia Microbiol* 43: 649–656

Sarma, T. A. , and Khattar, J. I. S. (1986a) Accumulation of cyanophycin and glycogen during sporulation in the blue-green alga *Anabaena torulosa*. *Biochem Physiol Pflanzen* 181: 155–164.

Sarma, T. A. , and Khattar, J. I. S. (1986b) Accumulation of reserve products during sporulation in *Anabaena torulosa* under phototrophic, photoheterotrophic and heterotrophic conditions. *Biochem Physiol Pflanzen* 181: 541–549.

Sarma, T. A. , and Khattar, J. I. S. (1992) Phosphorus deficiency, nitrogen assimilation and akinete differentiation in the cyanobacterium *Anabaena torulosa*. *Folia Microbiol* 37: 223–226.

Sarma, T. A. , and Khattar, J. I. S. (1993) Akinete differentiation in photoheterotrophic and chemoheterotrophic conditions in *Anabaena torulosa*. *Folia Microbiol* 38: 335–340.

Sarma, T. A. , and Khattar, J. I. S. (1994) Photoheterotrophic and chemoheterotrophic dinitrogen fixation and nitrate utilization by the cyanobacterium *Anabaena torulosa*. *Folia Microbiol* 39: 404–408.

Sarma, T. A. , and Malhotra, J. (1989) Induction of the formation of akinetes and microcycle akinetes in the cyanobacterium *Anabaena torulosa*. *Biochem Physiol Pflanzen* 184: 95–106.

Sarma, T. A. , and Mehta, M. (1985) Phosphate utilization and the activity of phosphatases during sporulation in two blue-green algae. *Biochem Physiol Pflanzen* 180: 401–405.

Sarma, T. A. , and Swarn Kanta (1979) Biochemical studies on sporulation in blue green algae. 1. Glycogen accumulation. *Z Allg Mikrobiol* 19: 571–575.

Sarma, T. A. , and Swarn Kanta (1980) Biochemical studies on sporulation in blue-green algae. III. Effect of amino acids on glycogen accumulation. *Z Allg Mikrobiol* 20: 647–650.

Sarma, T. A. , and Swarn Kanta (1982) Variation in enzyme levels during sporulation in blue-green algae. *Biochem Physiol Pflanzen* 177: 278–282.

Sarma, T. A. , Ahuja, G. , and Khattar, J. I. S. (2000) Effect of nutrients and aeration on O₂ evolution and photosynthetic pigments of *Anabaena torulosa*. *Folia Microbiol* 45: 434–438.

Sarma, T. A. , Ahuja, G. and Khattar, J. I. S. (2004) Nutrient stress causes akinete differentiation in cyanobacterium *Anabaena torulosa* with concomitant increase in nitrogen reserve substances. *Folia Microbiol* 49: 557–562.

Sarma, T. A. , Khattar, J. I. S. , Ahuja, G. , and Saini, V. (1998) Influence of aeration and nutrients on akinete differentiation in the cyanobacterium *Anabaena torulosa*. In: Subramanian, G. , Kaushik, B. D. , and Ventataraman, G. S. (Eds.) *Cyanobacterial Biotechnology*. Oxford and IBH Publishing Comp., New Delhi. pp. 99–102.

Sarma, T. A. , Swarn Kanta , Ahuja, B. S. , and Usha Kiran (1977) Amylase activity in a blue-green alga. *Curr Sci* 46: 609–610.

Sharma, P. (1984) Heterocyst and akinete induction with altered pattern in *Anabaena cylindrica* caused by neopeptone. *Arch Microbiol* 139: 196–201.

Shively, J. M. (1974) Inclusion bodies of prokaryotes. *Annu Rev Microbiol* 28: 167–187.

Sili, C. , Ena, A. , Materassi, R. , and Vincenzini, M. (1994) Germination of desiccated aged akinetes of alkaliphilic cyanobacteria. *Arch Microbiol* 162: 20–25.

Simon, R. D. (1977) Sporulation in the filamentous cyanobacterium, *Anabaena cylindrica*. The course of spore formation. *Arch Microbiol* 111: 283–288.

Sinclair, C. , and Whitton, B. A. (1977) Influence of nitrogen source on morphology of Rivulariaceae (Cyanophyta). *J Phycol* 13: 335–340.

Singh, H. N. (1967) Genetic control of sporulation in the blue-green alga *Anabaena doliolum*. *Bharadwaja. Planta* 75: 33–38.

Singh, H. N. , and Srivastava, B.S. (1968) Studies on morphogenesis in blue-green alga. I. Effect of inorganic nitrogen sources on developmental morphology of *Anabaena doliolum*. *Can J Microbiol* 14: 1342–1348.

Singh, H. N. , and Sunita, K. M. (1974) Biochemical study of spore germination in the blue-green alga *Anabaena doliolum*. *J Exp Bot* 25: 837–845.

Singh, R. N. , and Dikshit, R. P. (1976) Mutagenesis of blue-green alga, *Anabaena doliolum* Bharadwaja. *Mutat Res* 35: 65–78.

Singh, R. N. , and Sinha, R. (1965) Genetic recombination in a blue-green alga, *Cylindrospermum majus* Kuetz. *Nature (London)* 207: 782–783.

Singh, R. N. , and Tiwari, D. N. (1970) Frequent heterocyst germination in the blue-green alga, *Gloeotrichia ghosei* Singh. *J Phycol* 6: 172–176.

Singh, R. N. , Singh, S. P. and Singh, P. K. (1972a) Genetic regulation of nitrogen fixation in Blue-green Algae. In: Desikachary, T.V. (Ed.) *Taxonomy and Biology of Blue-green Algae*, University of Madras, Madras. pp. 263–268.

Singh, R. N. , Tiwari, D. N. , and Singh, V. P. (1972b) Genetic basis of cellular differentiation in blue-green algae. In: Desikachary, T.V. (Ed.) *Taxonomy and Biology of Blue-green Algae*, University of Madras, Madras. pp. 27–37.

Singh, S. , and Kashyap, A. K. (1988) Metabolic characteristics of akinetes of the cyanobacterium *Fischerella muscicola*. *New Phytol* 110: 97–100.

Singh, V. P. (1978) Mutations defective in nitrogen fixation, heterocyst and spore production in the blue-green alga, *Anabaena variabilis*. *Biochem Physiol Pflanzen* 174: 76–79.

Simon, R. D. (1977) Sporulation in the filamentous cyanobacterium *Anabaena cylindrica*. The course of spore formation. *Arch Microbiol* 111: 283–288.

Skill, S. C. , and Smith, R. J. (1987) Synchronous akinete germination and heterocyst differentiation in *Anabaena* PCC 7937 and *Nostoc* PCC 6720. *J Gen Microbiol* 133: 299–303.

Smith, A.J. (1982) Modes of cyanobacterial carbon metabolism. In: Carr, N. G. , and Whitton, B. A. (Eds.) *The Biology of Cyanobacteria*, Blackwell Scientific Publications, Oxford, UK pp. 47–85.

Srivastava, P. (2005) Vindhyana akinetes: An indicator of Mesoproterozoic biospheric evolution. *Origin of Life and Evolution of Biospheres* 33: 175–183.

- Stewart, W. D. P. (1980) Some aspects of structure and function in N₂-fixing cyanobacteria. *Annu Rev Microbiol* 34: 497–536.
- Stulp, B. K. , and Stam, W. T. (1982) General morphology and akinete germination of a number of *Anabaena* strains (Cyanophyceae) in culture. *Arch Hydrobiol Suppl* 63: 35–52.
- Sukenik, A. , Hadas, O. , Stojkovic, S. , Malinsky-Rushansky, N. , Vinter-Motzini, Y. , and Beardall, J. (2009) Fluorescence microscopy reveals variations in cellular composition during formation of akinetes in the cyanobacterium *Aphanizomenon ovalisporum*. *Eur J Phycol* 44: 309–317.
- Summons, R. E. , Jahnke, L. L. , Hope, J. M. , and Logan, G. A. (1999) 2-Methylhopanoids as biomarkers for cyanobacterial oxygenic photosynthesis. *Nature (London)* 400: 554–557.
- Sutherland, J. M. , Herdman, M. , and Stewart, W. D. P. (1979) Akinetes of the cyanobacterium *Nostoc* PCC 7524: Macromolecular composition, structure and control of differentiation. *J Gen Microbiol* 115: 273–287.
- Sutherland, J. M. , Herdman, M. , and Stewart, W. D. P. (1980) Structure and differentiation of akinetes and their relation to heterocysts of the cyanobacterium *Nostoc* PCC 7524. *Soc Gen Microbiol* 7: 105.
- Sutherland, J. M. , Reaston, J. , Stewart, W. D. P. , and Herdman, M. (1985a) Akinetes of the cyanobacterium *Nostoc* PCC 7524: Macromolecular and biochemical changes during synchronous germination. *J Gen Microbiol* 131: 2855–2863.
- Sutherland, J. M. , Stewart, W. D. P. , and Herdman, M. (1985b) Akinetes of the cyanobacterium, *Nostoc* PCC 7524. Morphological changes during synchronous germination. *Arch Microbiol* 142: 269–274.
- Swarn Kanta , and Sarma, T. A. (1980) Biochemical studies on sporulation in blue-green algae. II. Factors affecting glycogen accumulation. *Z Allg Mikrobiol* 20: 459–463.
- Swarn Kanta , Sarma, T. A. , and Ahuja, B. S. (1978) A kinetic study of amylase from a blue-green alga. *Indian J Exp Biol* 16: 1211–1212.
- Talpasayi, E. R. S. (1963) Polyphosphate containing particles of blue-green algae. *Cytologia* 28: 76–80.
- Tandeau De Marsac, N. and Houmard, J. (1996) Acclimation of the filamentous cyanobacteria *Calothrix* spp. to the environment: Physiological and molecular studies. In: Subramanian G. , Kaushik, B. D. , and Venkataraman, G. S. (Eds.) *Cyanobacterial Biotechnology* Oxford and IBH Publishing Co. Pvt. Ltd, New Delhi, India, pp. 215–224.
- Thiel, T. , and Wolk, C. P. (1983). Metabolic activities spores of *Nostoc spongiaeforme*. *J Bacteriol* 156: 369–374.
- Thompson, P. A. , Jameson, I. , and Blackburn, S. I. (2009) The influence of light quality on akinete formation and germination in the toxic cyanobacterium *Anabaena circinalis*. *Harmful Algae* 8: 504–512.
- Tsujimura, S. (2004) Reduction of germination frequency in *Anabaena* akinetes by sediment drying: A possible method by which to inhibit bloom formation. *Water Res* 38: 4361–4366.
- Tsujimura, S. , and Okubo, T. (2003) Development of *Anabaena* blooms in a small reservoir with dense sediment akinete population, with special reference to temperature and irradiance. *J Plankton Res* 25: 1059–1067.
- Tyagi, V. V. S. (1974) Some observations on the pattern of sporulation in the blue-green alga *Anabaena doliolum*. *Ann Bot* 38: 1107–1111.
- Ueda, K. , and Swada, M. (1972) DNA content of akinete cells in *Cylindrospermum*. *Cytologia* 37: 519–529.
- van Dok, W. , and Hart, B. T. (1996) Akinete differentiation in *Anabaena circinalis* (Cyanophyta) *J Phycol* 32: 557–565.
- van Dok, W. , and Hart, B. T. (1997) Akinete germination in *Anabaena circinalis* (Cyanophyta). *J Phycol* 33: 12–17.
- Wilden, D. C. , and Mercer, C. V. (1963) The ultrastructure of the heterocyst and akinete of the blue-green algae. *Arch Microbiol* 47: 19–31.
- Wildman, R. B. , Loescher, J. H. , and Winger, C. L. (1975) Development and germination of akinetes of *Aphanizomenon flos-aquae*. *J Physiol* 11: 96–104.
- Wolk, C.P. (1965) Control of sporulation in a blue-green alga. *Develop Biol* 12: 15–35.
- Wolk, C. P. (1966) Evidence of a role of heterocysts in the sporulation of a blue-green alga. *Am J Bot* 53: 260–262.
- Wolk, C. P. (1973) Physiology and cytological chemistry of blue-green algae. *Bacteriol Rev* 37: 32–101.
- Wolk, C. P. , and Simon, R. D. (1969) Pigments and lipids of heterocysts. *Planta* 86: 92–97.
- Wolk, C. P. , Ernst, A. , and Elhai, J. (1994) Heterocyst metabolism and development. In: Bryant D. E. (Ed.) *The Molecular Biology of Cyanobacteria*. Kluwer Academic, Dordrecht, The Netherlands. pp. 769–823.
- Wong, F. C. , and Meeks, J. C. (2002) Establishment of a functional symbiosis between the cyanobacterium *Nostoc punctiforme* and the bryophyte hornwort *Anthoceros punctatus* requires genes involved in nitrogen control and initiation of heterocyst differentiation. *Microbiology* 148: 315–323.
- Wyman, M. , and Fay, P. (1986) Interaction between light quality and nitrogen availability in the differentiation of akinetes in the planktonic cyanobacterium *Gloeotrichia echinulata*. *Br Phycol J* 21: 147–154.
- Yamamoto, Y. (1975) Effect of desiccation on the germination of akinetes of *Anabaena cylindrica*. *Plant Cell Physiol* 16: 749–752.
- Yamamoto, Y. (1976) Effect of some physical and chemical factors of the germination of akinetes of *Anabaena cylindrica*. *J Gen Appl Microbiol* 22: 311–323.
- Zhou, R. , and Wolk, C. P. (2002) Identification of an akinete marker gene in *Anabaena variabilis*. *J Bacteriol* 184: 2529–2532.

Heterocyst

- Aboulmagd, E. , Oppermann-Sanio, F. B. , and Steinbüchel, A. (2000) Molecular characterization of the cyanophycin synthetase from *Synechocystis* sp. strain PCC 6803. *Arch Microbiol* 174: 297–306.
- Aboulmagd, E. , Oppermann-Sanio, F. B. , and Steinbüchel, A. (2001) Purification of *Synechocystis* sp. strain PCC 6803 cyanophycin synthetase and its characterization with respect to substrate and primer specificity. *Appl Environ Microbiol* 67: 2176–2182. Doi:10.1128/AEM.6752176-2182.2001
- Abreu-Grobois, F. A. , Billyard, T. C. , and Walton, T. J. (1977) Biosynthesis of heterocyst glycolipids of *Anabaena cylindrica*. *Phytochemistry* 16: 351–354.
- Adams, D. G. (1992) The effect of 7-azatryptophan on heterocyst development in the cyanobacterium *Anabaena cylindrica*. *J Gen Microbiol* 138: 335–362.
- Adams, D. G. (2000) Heterocyst formation in cyanobacteria. *Curr Opin Microbiol* 3: 618–624.

Adams, D. G. , and Carr, N. G. (1981) Heterocyst differentiation and cell division in the cyanobacterium *Anabaena cylindrica*. Effect of high light intensity. *J Cell Sci* 49: 341–352.

Adams, D. G. , and Carr, N. G. (1989) Control of heterocyst development in the cyanobacterium *Anabaena cylindrica*. *J Gen Microbiol* 135: 839–849.

Adams, D. G. , and Duggan, P. S. (1999) Heterocyst and akinete differentiation in cyanobacteria. *Tansley Review No. 107. New Phytol* 144: 3–33.

Agervald, Å. , Stensjö, K. , Holmqvist, M. , and Lindblad, P. (2008) Transcription of the extended hyp-operon in *Nostoc* PCC 7120. *BMC Microbiol* 8: 69. doi:10.1186/1471-2180-8-69

Agrawal, M. , and Kumar, H. D. (1978) Effect of 7-azatryptophan on heterocyst differentiation in *Anabaena doliolum* Bharadwaja. *Proc Indian Acad Sci* 87: 31–39.

Aldea, M. R. , Mella-Herrera, R. A. , and Golden, J. W. (2007) Sigma factor genes sigC, sigE and sigG are upregulated in heterocysts of the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 189: 8392–8396.

Aldehni, M. F. , and Forchhammer, K. (2006) Analysis of a non-canonical NtcA-dependent promoter in *Synechococcus elongatus* and its regulation by NtcA and PII. *Arch Microbiol* 184: 378–386.

Aldehni, M. F. , Sauer, J. , Spielhaupter, C. , Schmid, R. , and Forchhammer, K. (2003) Signal transduction protein P(II) is required for NtcA-regulated gene expression during nitrogen deprivation in the cyanobacterium *Synechococcus elongatus* strain PCC 7942. *J Bacteriol* 185: 2582–2591.

Alfonso, M. , Perewoska, I. , and Kirilovsky, D. (2001) Redox control of ntcA gene expression in *Synechocystis* sp. strain PCC 6803. Nitrogen availability and electron transport regulate the levels of the NtcA protein. *Plant Physiol* 125: 969–981.

Alge, D. , and Peschek, G. A. (1993) Identification and characterization of the ctaC (coxB) gene as part of an operon encoding subunits I, II, and III of the cytochrome c oxidase (cytochrome aa3) in the cyanobacterium *Synechocystis* PCC 6803. *Biochem Biophys Res Commun* 191: 9–17.

Alge, D. , Wastyn, M. , Mayer, C. , Jungwirth, C. , Zimmermann, U. , Zoder, R. , Fromwald, S. , and Peschek, G. A. (1999) Allosteric properties of cyanobacterial cytochrome c oxidase: Inhibition of the coupled enzyme by ATP and stimulation by ADP. *IUBMB Life* 48: 187–197.

Allard, J. F. , Hill, A. L. , and Rutenberg, A. D. (2007) Heterocyst patterns without patterning proteins in cyanobacterial filaments. *Develop Biol* 312: 427–434.

Allen, M. M. (1984) Cyanobacterial cell inclusions. *Annu Rev Microbiol* 38: 1–25.

Allen, M. M. , and Hawley, M. A. (1983) Protein degradation and synthesis of cyanophycin granule polypeptide in *Anabaena* sp. *J Bacteriol* 154: 1480–1484.

Allen, M. M. , and Hutchison, F. (1980) Nitrogen limitation and recovery in the cyanobacterium *Aphanocapsa* 6308. *Arch Microbiol* 128: 1–7.

Allen, M. M. , and Smith, A. J. (1969) Nitrogen chlorosis in blue-green algae. *Arch Microbiol* 69: 114–120.

Allen, M. M. , Hutchinson, F. , and Weathers, P. J. (1980) Cyanophycin granule polypeptide formation and degradation in the cyanobacterium *Aphanocapsa* 6308. *J Bacteriol* 141: 687–693.

Allen, M. M. , Yuen, C. , Medeiros, L. , Zizlsperger, N. , Farooq, M. , and Koloday, N. H. (2005) Effect of light and chloramphenicol stress incorporation of nitrogen into cyanophycin in *Synechocystis* sp. strain PCC 6803. *Biochim Biophys Acta* 1725: 241–246.

Almon, H. , and Böhme, H. (1980) Components and activity of photosynthetic electron transport system of intact heterocysts isolated from the blue-green alga *Nostoc muscorum*. *Biochim Biophys Acta* 592: 113–120.

Almon, H. , and Böger, P. (1984) Ni-dependent uptake hydrogenase activity in the blue-green alga *Anabaena variabilis*. *Z Naturforsch* 39: 90–92.

Andersen, J. B. , Sternberg, C. , Poulsen, L. K. , Bjorn, S. P. , Givskov, M. , and Molin, S. (1998) New unstable variants of green fluorescent protein for studies of transient gene expression in bacteria. *Appl Environ Microbiol* 64: 2240–2246.

Apte, S. K. , Rowell, P. , and Stewart, W. D. P. (1978) Electron donation to ferredoxin in heterocysts of the N₂-fixing alga *Anabaena cylindrica*. *Proc R Soc B London* 200: 1–25.

Aravind, L. , and Koonin, E. V. (2002) Classification of the capsase-hemoglobinase fold: Detection of new families and implications for the origin of the eukaryotic separins. *Proteins* 46: 355–387.

Arcondéguy, T. , Jack, R. , and Merrick, M. (2001) PII signal transduction proteins, pivotal players in microbial nitrogen control. *Microbiol Mol Biol Rev* 65: 80–105.

Argueta, C. , Yukes, K. , and Summers, M. (2004) Construction and use of GFP reporter vectors for analysis of cell-type-specific gene expression in *Nostoc punctiforme*. *J Microbiol Methods* 59: 181–188.

Asada, Y. , Kawamura, S. , and Ho, K.-K. (1987) Hydrogenase from the unicellular cyanobacterium, *Microcystis aeruginosa*. *Phytochemistry* 26: 637–640.

Asai, H. , Iwamori, S. , Kawai, K. , Ehira, S. , Ishihara, J.-i. , Aihara, K. , Shoji, S. , and Iwasaki, H. (2009) Cyanobacterial cell lineage analysis of the spatio-temporal hetR expression profile during heterocyst pattern formation in *Anabaena* sp. PCC 7120. *PLoS ONE* 4: e7371. doi:10.1371/journal.pone.007371.

Asayama, M. , Imamura, S. , Yoshihara, S. , Miyazaki, A. , Yoshida, N. , Sazuka, T. , Kaneko, T. , Ohara, O. , Tabata, S. , Osanai, T. , Tanaka, K. , Takahashi, H. , and Shirai, M. (2004) SigC, the group 2 sigma factor of RNA polymerase contributes to the late-stage gene expression and nitrogen promoter recognition in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *Biosci Biotechnol Biochem* 68: 477–487.

Awai, K. , Lechno-Yossef, S. , and Wolk, C. P. (2009) Heterocyst glycolipids. In: *Lipids in Photosynthesis. Adv Photosynth Resp* 30: 179–202.

Axelsson, R. , and Lindblad, P. (2002) Transcriptional regulation of *Nostoc* hydrogenases: Effects of oxygen, hydrogen and nickel. *Appl Environ Microbiol* 68: 444–447.

Axelsson, R. , Oxelfelt, F. , and Lindblad, P. (1999) Transcriptional regulation of *Nostoc* uptake hydrogenase. *FEMS Microbiol Lett* 170: 77–81.

Bahal, M. , and Talpasayi, E. R. S. (1970a) Heterocyst differentiation in *Anabaena ambigua* Rao. III. Effect of Thiol inhibitors. *Indian Biologist* 2: 56–65.

Bahal, M. , and Talpasayi, E. R. S. (1970b) Effect of azide and glycine on heterocyst development in *Anabaena ambigua* Rao. *Indian J Exp Biol* 8: 237–238.

Baier, K. , Lehmann, H. , Stephan, D. P. , and Lockau, W. (2004) NblA is essential for phycobilisome degradation in *Anabaena* sp. strain PCC 7120 but not for development of functional heterocysts. *Microbiology* 150: 2739–2749.

Baier, K. , Nicklisch, S. , Grundner, C. , Reinecke, J. , and Lockau, W. (2001) Expression of two nblA-homologous genes is required for phycobilisome degradation in nitrogen-starved *Synechocystis* sp. PCC 6803. *FEMS Microbiol Lett* 195: 35–39.

Baker, P. J. , Sawa, Y. , Shibata, H. , Sedelnikova, S. E. , and Rice, D. W. (1998) Analysis of the structure and substrate binding of Phormidium lapideum alanine dehydrogenase. *Nat Struct Biol* 5: 561–567.

Barnum, S. R. , and Gendel, S. M. (1985) Organization of nitrogen fixation genes in a nonheterocystous, filamentous cyanobacterium. *FEMS Microbiol Lett* 29: 339–342.

Bastet, L. , Boileau, C. , Bédou, S. , Janicki, A. , Latifi, A. , and Zhang, C.-C. (2010) NtcA regulates patA expression in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 192: 5257–5259.

Bauer, C. C. , Buikema, W. J. , Black, K. , and Haselkorn, R. (1995) A short-filament mutant of *Anabaena* sp. strain PCC 7120 that fragments in nitrogen-deficient medium. *J Bacteriol* 177: 1520–1526.

Bauer, C. C. , Ramaswamy, K. S. , Endley, S. , Scappino, L. A. , Golden, J. W. , and Haselkorn, R. (1997) Suppression of heterocyst differentiation in *Anabaena* PCC 7120 by a cosmid carrying wild-type genes encoding enzymes for fatty acid synthesis. *FEMS Microbiol Lett* 151: 23–30.

Bauersachs, T. , Compaoré, J. , Hopmans, E. C. , Stal, L. J. , Schouten, S. , and Sinninghe Damsté, S. (2009) Distribution of heterocyst glycolipids in cyanobacteria. *Phytochemistry* 70: 2034–2039.

Bauersachs, T. , Speelman, E. N. , Hopmans, E. C. , Reichart, G. J. , Schouten, S. , and Sinninghe Damsté, J. S. (2010) Fossilized glycolipids reveal past oceanic N₂ fixation by heterocystous cyanobacteria. *Proc Natl Acad Sci USA* 107: 19190–19194.

Becker, D. W. , and Brand, J. J. (1985) *Anacystis nidulans* demonstrates a photosystem II cation requirement satisfied only by Ca²⁺ or Na⁺. *Plant Physiol* 79: 552–558.

Bergman, B. , and Rai, A. (1989) The Nostoc-Nephroma symbiosis: Localization, distribution pattern and levels of key proteins involved in nitrogen and carbon metabolism of the cyanobiont. *Physiol Plant* 77: 216–224.

Bergman, B. , Siddiqui, P. J. A. , Carpenter, E. J. , and Peschek, G. A. (1993) Cytochrome oxidase: Subcellular distribution and relation to nitrogenase expression in the nonheterocystous marine cyanobacterium *Trichodesmium thiebautii*. *Appl Environ Microbiol* 59: 3239–3244.

Bienert, R. , Baier, K. , Volkmer, R. , Lockau, W. , and Heinemann, U. (2005) Crystal structure of NblA from *Anabaena* sp. PCC 7120, a small protein playing a key role in phycobilisome degradation. *J Biol Chem* 281: 5216–5223.

Black, K. , Buikema, W. J. , and Haselkorn, R. (1995) The hglK gene is required for localization of heterocyst-specific glycolipids in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 177: 6440–6448.

Black, T. A. , and Wolk, C. P. (1994) Analysis of a Het⁻ mutation in *Anabaena* sp. strain PCC 7120 implicates a secondary metabolite in the regulation of heterocyst spacing. *J Bacteriol* 176: 2282–2292.

Black, T. A. , Cai, Y. , and Wolk, C. P. (1993) Spatial expression and autoregulation of hetR, a gene involved in the control of heterocyst development in *Anabaena*. *Mol Microbiol* 9: 77–84.

Boison, G. , Böthe, H. , and Schmitz, D. (2000) Transcriptional analysis of hydrogenase genes in the cyanobacteria *Anacystis nidulans* and *Anabaena variabilis* monitored by RT-PCR. *Curr Microbiol* 40: 315–321.

Böhme, H. (1987) Regulation of electron flow to nitrogenase in a cell free system from heterocysts of *Anabaena variabilis*. *Biochim Biophys Acta* 891: 121–128.

Böhme, H. , and Almon, H. (1983) Reactions of hydrogen and oxygen with photosystem I of isolated heterocysts from *Anabaena variabilis* (ATCC 29413). *Biochim Biophys Acta* 722: 401–407.

Böhme, H. , and Ernst, A. (1984) Redox reactions of cytochrome b-564 and f-556 in isolated heterocysts of *Anabaena variabilis* (ATCC 29413). *Adv Photosynth Res* 2: 639–642.

Böhme, H. , and Haselkorn, R. (1988) Molecular cloning and nucleotide sequence analysis of the gene coding for heterocyst ferredoxin from the cyanobacterium *Anabaena* sp. strain PCC 7120. *Mol Gen Genetics* 214: 278–285.

Böhme, H. , and Schrautemeier, B. (1987) Comparative characterization of ferredoxins from heterocysts and vegetative cells of *Anabaena variabilis*. *Biochim Biophys Acta* 891: 1–7.

Boresch, K. (1910) Zur Physiologie der Blaualgenfarbstoffe. *Lotos (Prague)* 58: 344–345.

Bornet, E. , and Flahault, C. (1886) Révision des Nostocacées. Reprint 1959. Cramer, Weinheim.

Bornet, E. , and Thuret, G. (1880) Notes Algologiques. II. G. Masson, Paris.

Borthakur, D. , and Haselkorn, R. (1989) The mutagenesis of *Anabaena* sp. strain PCC 7120: Isolation of a new mutant unable to grow without combined nitrogen. *J Bacteriol* 171: 5759–5761.

Borthakur, P. B. , Orozco, C. C. , Young-Robbins, S. S. , Haselkorn, R. , and Callahan, S. M. (2005) Inactivation of patS and hetN causes lethal levels of heterocyst differentiation in the filamentous cyanobacterium *Anabaena* sp. PCC 7120. *Mol Microbiol* 57: 111–123.

Bothe, H. (1970) Photosynthetische Stickstofffixierung mit einem zellfreien Extrakt aus der Blaualge *Anabaena cylindrica*. *Ber Dtsch Bot Ges* 83: 421–432.

Bothe, H. (1982) Nitrogen fixation In: Carr, N. G. and Whitton, B. A. (Eds.) *The Biology of Cyanobacteria*. Blackwell Scientific Publications, Oxford, UK pp. 87–104.

Bothe, H. , and Eisbrenner, G. (1977). Effect of 7-azatryptophan on nitrogen fixation and heterocyst formation in the blue-green alga *Anabaena cylindrica*. *Biochem Physiol Pflanzen* 171: 322–332.

Bothe, H. , Neuer, G. , Kalbe, I. , and Eisbrenner, G. (1980) Electron donors and hydrogenase in nitrogen fixing microorganisms. In: Stewart, W. D. P. and Gallon, J. R. (Eds.) *Nitrogen Fixation*. Academic Press, New York, NY, USA pp. 83–112.

Bothe, H. , Tennigkeit, J. , and Eisbrenner, G. (1977) The utilization of molecular hydrogen by the blue-green alga *Anabaena cylindrica*. *Arch Microbiol* 114: 43–49.

Bottomley, P. J. , Van Baalen, C. , and Tabita, F. R. (1980) Heterocyst differentiation and tryptophan metabolism in the cyanobacterium *Anabaena* sp. CA. *Arch Biochem Biophys* 203: 204–213.

Bradley, S. , and Carr, N. G. (1976) Heterocyst and nitrogenase development in *Anabaena cylindrica*. *J Gen Microbiol* 96: 175–184.

Brahamsha, B. , and Haselkorn, R. (1991) Isolation and characterization of the gene encoding the principal sigma factor of the vegetative cell RNA polymerase from the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 173: 2442–2450.

Brahamsha, B. , and Haselkorn, R. (1992) Identification of multiple RNA polymerase sigma factor homologs in the cyanobacterium *Anabaena* sp. strain PCC 7120: Cloning, expression, and inactivation of the sigB and sigC genes. *J Bacteriol* 174: 7273–7282.

Braun-Howland, E. B. , Lindblad, P. , Nierzwicki-Bauer, S. A. , and Bergman, B. (1988) Dinitrogenase reductase (Fe-protein) of nitrogenase in the cyanobacterial symbionts of three *Azolla* species: Localization and sequence of appearance during heterocyst differentiation. *Planta* 176: 319–322.

Brusca, J. S. , Chastain, C. J. , and Golden, J. W. (1990) Expression of the *Anabaena* sp. strain PCC 7120 *xisA* gene from a heterologous promoter results in excision of the *nifD* element. *J Bacteriol* 172: 3925–3931.

Brusca, J. S. , Hale, M. A. , Carrasco, C. D. , and Golden, J. W. (1989) Excision of an 11-kilobase-pair DNA element from within the *nifD* gene in *Anabaena variabilis* heterocysts. *J Bacteriol* 171: 4138–4145.

Bryce, T. A. , Weln, D. , Walsby, A. E. , and Nichols, B. W. (1972) Monohexoside derivatives of long-chain polyhydroxyalcohols: a novel class of glycolipids specific to heterocystous algae. *Phytochemistry* 11: 295–302.

Buikema, W. J. , and Haselkorn, R. (1991a) Isolation and complementation of nitrogen fixation mutants of the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 173: 1879–1885.

Buikema, W. J. , and Haselkorn, R. (1991b) Characterization of a gene controlling heterocyst differentiation in the cyanobacterium *Anabaena* 7120. *Genes Dev* 5: 321–330.

Buikema, W. J. , and Haselkorn, R. (2001) Expression of the *Anabaena* *hetR* gene from a copper-regulated promoter leads to heterocyst differentiation under repressing conditions. *Proc Natl Acad Sci USA* 98: 2729–2734.

Cai, Y. , and Wolk, C. P. (1997) *Anabaena* sp. strain PCC 7120 responds to nitrogen deprivation with a cascade-like sequence of transcriptional activations. *J Bacteriol* 179: 267–271.

Callahan, S. M. , and Buikema, W. J. (2001) The role of *HetN* in maintenance of the heterocyst pattern in *Anabaena* sp. PCC 7120. *Mol Microbiol* 40: 941–950.

Calusinska, M. , Happe, T. , Joris, B. , and Wilmutte, A. (2010) The surprising diversity of clostridial hydrogenases: A comparative genomic perspective. *Microbiology* 156: 1575–1588.

Campbell, E. L. , Brahamsha, B. , and Meeks, J. C. (1998) Mutation of an alternative sigma factor in the cyanobacterium *Nostoc punctiforme* results in an increased infection of its symbiotic plant partner, *Anthoceros punctatus*. *J Bacteriol* 180: 4938–4941.

Campbell, E. L. , Cohen, M. F. , and Meeks, J. C. (1997) A polyketide-synthase-like gene is involved in the synthesis of heterocyst glycolipids in *Nostoc punctiforme* strain ATCC 29133. *Arch Microbiol* 167: 251–258.

Campbell, E. L. , Hagen, K. D. , Cohen, M. F. , Summers, M. L. , and Meeks, J. C. (1996) The *devR* gene product is characteristic of receivers of two-component regulatory systems and is essential for heterocyst development in the filamentous cyanobacterium *Nostoc* sp. strain PCC 29133. *J Bacteriol* 178: 2037–2043.

Campbell, E. L. , Summers, M. L. , Christman, H. , Martin, M. E. , and Meeks, J. E. (2007) Global gene expression patterns of *Nostoc punctiforme* in steady-state dinitrogen-grown heterocyst containing cultures and at single time points during differentiation of akinetes and hormogonia. *J Bacteriol* 189: 5247–5256.

Canabaeus, L. (1929) Über die Heterocysten und Gasvaakuolen der Blaualgen und ihre Beziehungen zueinander. In: Kolkowitz, R. (Ed.) *Pflanzenforschung*. Vol 13, Jena, Fischer. pp. 1–48.

Cardemil, L. , and Wolk, C. P. (1979) The polysaccharides from heterocyst and spore envelopes of a blue-green alga: Structure of the basic repeating unit. *J Biol Chem* 254: 736–741.

Cardemil, L. , and Wolk, C. P. (1981a) Polysaccharides from the envelopes of heterocysts and spores of the blue-green algae *Anabaena variabilis* and *Cylindrospermum licheniforme*. *J Phycol* 17: 234–240.

Cardemil, L. , and Wolk, C. P. (1981b) Isolated heterocysts of *Anabaena variabilis* synthesize envelope polysaccharide. *Biochim Biophys Acta* 674: 265–276.

Carpenter, E. J. , Bergman, B. , Dawson, R. , Siddiqui, P. J. , Soderback, E. , and Capone, D. G. (1992) Glutamine synthetase and nitrogen cycling in colonies of the marine diazotrophic cyanobacteria *Trichodesmium* spp. *Appl Environ Microbiol* 58: 3122–3129.

Carr, N. G. (1988) Nitrogen reserves and dynamic reservoirs in cyanobacteria. In: Rogers, L. J. , and Gallon, J. R. (Eds.) *Biochemistry of the Algae and Cyanobacteria*. Clarendon Press, Oxford, U.K. pp. 13–39.

Carrasco, C. D. , Buettner, J. A. , and Golden, J. W. (1995) Programmed DNA rearrangement of a cyanobacterial *hupL* gene in heterocysts. *Proc Natl Acad Sci USA* 92: 791–795.

Carrasco, C. D. , Holliday, S. D. , Hansel, A. , Lindblad, P. , and Golden, J. W. (2005) Heterocyst-specific excision of the *Anabaena* sp. strain PCC 7120 *hupL* element requires *xisC*. *J Bacteriol* 187: 6031–6038.

Carrasco, C. D. , Ramaswamy, K. S. , Ramasubramanian, T. S. , and Golden, J. W. (1994) *Anabaena* *xisF* gene encodes a developmentally regulated site-specific recombinase. *Genes Dev* 8: 74–83.

Chapman, J. S. , and Meeks, J. C. (1983) Glutamine and glutamate transport by *Anabaena variabilis*. *J Bacteriol* 156: 122–129.

Chastain, C. J. , Brusca, J. S. , Ramasubramanian, T. S. , Wei, T. F. , and Golden, J. W. (1990) A sequence-specific DNA-binding factor (VF1) from *Anabaena* sp. strain PCC 7120 vegetative cells binds to three adjacent sites in the *xisA* upstream region. *J Bacteriol* 172: 5044–5051.

Chen, C. , Van Baalen, C. , and Tabita, F. R. (1987) Nitrogen starvation mediated by DL-7-azatryptophan in the cyanobacterium *Anabaena* sp. strain CA. *J Bacteriol* 169: 1107–1113.

Chen, Y-F. , Motteux, O. , Bédu, S. , Li, Y.-Z. , and Zhang, C. C. (2011) Characterization of two critical residues in the effector domain of NtcA in the cyanobacterium *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 63: 32–38.

Codd, G. A. , Okabe, K. , and Stewart, W. D. P. (1980) Cellular compartmentation of photosynthetic and photorespiratory enzymes in the heterocystous cyanobacterium *Anabaena cylindrica*. *Arch Microbiol* 124: 149–154.

Cohen, M. F. , Wallis, J. G. , Campbell, E. L. , and Meeks, J. C. (1994) Transposon mutagenesis of *Nostoc* sp. strain ATCC 29133, a filamentous cyanobacterium with multiple cellular differentiation alternatives. *Microbiology* 140: 3233–3240.

Collier, J. L. , and Grossman, A. R. (1994) A small polypeptide triggers complete degradation of light-harvesting phycobiliproteins in nutrient-deprived cyanobacteria. *Embo J* 13: 1039–1047.

Crespo, J. L. , García-Domínguez, M. , and Florencio, F. J. (1998) Nitrogen control of the *glnN* gene that codes for GS type III, the only glutamine synthetase in the cyanobacterium *Pseudoanabaena* sp. PCC 6903. *Mol Microbiol* 30: 1101–1112.

Cumino, A. , Curatti, L. , Giarocco, L. , and Salerno, G. L. (2002) Sucrose metabolism: *Anabaena* sucrose-phosphate synthase and sucrose-phosphate phosphatase define minimal functional domains shuffled during evolution. *FEBS Lett* 517: 19–23.

Cumino, A. , Ekeröth, C. , and Salerno, G. L. (2001) Sucrose-phosphate phosphatase from *Anabaena* sp. strain PCC 7120: Isolation of the protein and gene revealed significant structural differences from the higher-plant enzyme. *Planta* 214: 250–256.

Cumino, A. , Marcozzi, C. , Barreiro, R. , and Salerno, G. (2007) Carbon cycling in *Anabaena* sp. PCC 7120. Sucrose synthesis in the heterocysts and possible role in nitrogen fixation. *Plant Physiol* 143: 1385–1397.

Cumino, A. C. , Perez-Cenci, M. , Giarrocco, L. E. , and Salerno, G. L. (2010) The proteins involved in sucrose synthesis in the marine cyanobacterium *Synechococcus* sp. PCC 7002 are encoded by two genes transcribed from a gene cluster. *FEBS Lett* 584: 4655–4660.

Curatti, L. , Flores, E. , and Salerno, G. (2002) Sucrose is involved in the diazotrophic metabolism of the heterocyst-forming cyanobacterium *Anabaena* sp. *FEBS Lett* 513: 175–178.

Curatti, L. , Folco, E. , Desplats, P. , Abratti, G. , Limones, V. , Herrera-Estrella, L. , and Salerno, G. L. (1998) Sucrose-phosphate synthase from *Synechocystis* sp. PCC 6803: Identification of the *spsA* gene and characterization of the enzyme expressed in *E. coli*. *J Bacteriol* 180: 6776–6779.

Curatti, L. , Giarrocco, L. , and Salerno, G. L. (2006) Sucrose synthase and RuBisCO expression is similarly regulated by the nitrogen source in the nitrogen fixing cyanobacterium *Anabaena* sp. *Planta* 223: 891–900.

Curatti, L. , Giarrocco, L. E. , Cumino, A. C. , and Salerno, G. L. (2008) Conversion of sucrose to polysaccharides in filamentous nitrogen fixing cyanobacteria. *Planta* 228: 617–625.

Curatti, L. , Porchia, A. C. , Herrera-Estrella, L. , and Salerno, G. L. (2000) A prokaryotic sucrose synthase gene (*susA*) isolated from a filamentous nitrogen fixing cyanobacterium encodes a protein similar to those of plants. *Planta* 211: 729–735.

Currier, T. C. , Huay, J. F. , and Wolk, C. P. (1977) Isolation and preliminary characterization of auxotrophs of a filamentous cyanobacterium. *J Bacteriol* 129: 1556–1562.

Daday, A. , and Smith, G. D. (1983) The effect of nickel on the hydrogen metabolism of the cyanobacterium *Anabaena cylindrica*. *FEMS Microbiol Lett* 20: 327–330.

Daday, A. , Mackerras, A. H. , and Smith, G. D. (1985) The effect of nickel on hydrogen metabolism and nitrogen fixation in the cyanobacterium *Anabaena cylindrica*. *J Gen Microbiol* 131: 231–238.

Daday, A. , Platz, R. , and Smith, G. D. (1977) Anaerobic and aerobic hydrogen gas formation by the blue-green alga *Anabaena cylindrica*. *Appl Environ Microbiol* 34: 478–483.

Desikachary, T. V. (1946) Germination of the heterocysts in two members of the Rivulariaceae. *J Indian Bot Soc* 25: 11–17.

Desikachary, T. V. (1959) *Cyanophyta*. Indian Council of Agricultural Research, New Delhi.

de Wet, J. R. , Wood, K. V. , Helinski, D. R. , and DeLuca, M. (1985) Cloning of firefly luciferase cDNA and the expression of active luciferase in *Escherichia coli*. *Proc Natl Acad Sci USA* 82: 7870–7873.

Dharmawardene, M. W. N. , Haystead, A. , and Stewart, W. D. P. (1973) Glutamine synthetase of the nitrogen-fixing alga *Anabaena cylindrica*. *Arch Microbiol* 90: 281–295.

Dines, M. , Sendersky, E. , David, L. , Schwarz, R. , and Adir, N. (2008) Structural, functional and mutational analysis of the NblA protein provides insight into possible modes of interaction with the phycobilisome. *J Biol Chem* 283: 30330–30340.

Doherty, H. M. , and Adams, D. G. (1995) Cloning and sequence of *ftsZ* and flanking regions from the cyanobacterium *Anabaena* PCC 7120. *Gene* 163: 93–96.

Dolganov, N. , and Grossman, A. R. (1993) Insertional inactivation of genes to isolate mutants of *Synechococcus* sp. strain PCC 7942: Isolation of filamentous strains. *J Bacteriol* 175: 7644–7651.

Dong, Y. , Huang, X. , Wu, X. Y. , and Zhang, J. (2000) Identification of active site of HetR protease and its requirement for heterocyst differentiation in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 182: 1575–1579.

Drawert, H. , and Metzner, I. (1956) Fluoreszenz und elektronen mikroskopische Beobachtungen an *Cylindrospermum* und anderen Cyanophyceen. *Ber Beutesch Bot Ges* 69: 291–301.

Dunn, J. H. , and Wolk, C. P. (1970) Composition of cellular envelopes of *Anabaena cylindrica*. *J Bacteriol* 103: 153–158.

Dunn, J. H. , Simon, R. D. , and Wolk, C. P. (1971) Incorporation of amino sugars into walls during heterocyst differentiation. *Develop Biol* 26: 159–164.

Duyvesteyn, M. G. C. , Korsuize, J. , de Waard, A. , Vonshak, A. , and Wolk, C. P. (1983) Sequence-specific endonucleases in strains of *Anabaena* and *Nostoc*. *Arch Microbiol* 134: 276–281.

Ehira, S. , and Ohmori, M. (2006a) NrrA, a nitrogen-responsive regulator facilitates heterocyst development in the cyanobacterium *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 59: 1692–1703.

Ehira, S. , and Ohmori, M. (2006b) NrrA directly regulates expression of hetR during heterocyst differentiation in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 188: 8520–8525.

Ehira, S. , Ohmori, M. , and Sato, N. (2003) Genome-wide expression analysis of the responses to nitrogen deprivation in the heterocyst-forming cyanobacterium *Anabaena* sp. strain PCC 7120. *DNA Res* 10: 97–113.

Eisbrenner, G. , Distler, E. , Floener, L. , and Böthe, H. (1978) The occurrence of the hydrogenase in some blue-green algae. *Arch Microbiol* 118: 177–184.

Elhai, J. , and Wolk, C. P. (1988) Conjugal transfer of DNA to cyanobacteria. *Methods Enzymol* 167: 747–754.

Elhai, J. , and Wolk, C. P. (1990) Developmental regulation and spatial pattern of expression of structural genes for nitrogenase in the cyanobacterium *Anabaena*. *Embo J* 9: 3379–3388.

Elhai, J. , Veprikitskiy, A. , Muro-Pastor, A. M. , Flores, E. , and Wolk, C. P. (1997) Reduction of conjugal transfer efficiency by three restriction activities of *Anabaena* sp. strain PCC 7120. *J Bacteriol* 179: 1998–2005.

El-Shehawey, R. , Lugomela, C. , Ernst, A. , and Bergman, B. (2003) Diurnal expression of hetR and diazocyte development in the filamentous non-heterocystous cyanobacterium *Trichodesmium erythraeum*. *Microbiology* 149: 1139–1146.

Ernst, A. , and Böger, P. (1985) Glycogen accumulation and the induction of nitrogenase activity in the heterocyst-forming cyanobacterium *Anabaena variabilis*. *J Gen Microbiol* 131: 3147–3153.

Ernst, A. , Reich, S. , and Böger, P. (1990) Modification of dinitrogenase reductase in the cyanobacterium *Anabaena variabilis* due to C starvation and ammonia. *J Bacteriol* 172: 748–755.

Ernst, A. , Black, T. , Cai, Y. , Panoff, J.-M. , Tiwari, D. N. , and Wolk, C. P. (1992) Synthesis of nitrogenase in mutants of the cyanobacterium *Anabaena* sp. strain PCC 7120 affected in heterocyst development or metabolism. *J Bacteriol* 174: 6025–6032.

England, R. R. , and Evans, E. H. (1983) A requirement for Ca²⁺ in O₂-evolving photosystem 2 preparations from the cyanobacterium, *Anacystis nidulans*. *Biochem J* 201: 473–476.

Espinosa, J. , Brunner, T. , Fiedler, N. , Forchhammer, K. , Muro-Pastor, A. M. , and Maldener, I. (2010) DevT (Alr4674), resembling a Ser/Thr protein phosphatase, is essential for heterocyst function in the cyanobacterium *Anabaena* sp. PCC 7120. *Microbiology* 156: 3544–3555.

Espinosa, J. , Forchhammer, K. , Burillo, S. , and Contreras, A. (2006) Interactive network in cyanobacterial nitrogen regulation: PipX, a protein that interacts in a 2-oxoglutarate dependent manner with PII and NtcA. *Mol Microbiol* 61: 457–469. doi:10.1111j.1365-2598.2006.05231

Falah Hamadi, A. , and Gallon, J. R. (1981) Calcium ions, oxygen and acetylene reduction (nitrogen fixation) in *Gloeocapsa* sp. 1430/3. *J Gen Microbiol* 125: 391–398.

Fan, O. , Huang, G. , Lechno-Yossef, S. , Wolk, C. P. , Kaneko, T. , and Tabata, S. (2005) Clustered genes required for synthesis and deposition of envelope glycolipids in *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 58: 227–243.

Fan, O. , Lechno-Yossef, S. , Ehira, S. , Kaneko, T. , Ohmori, M. , Sato, N. , Tabata, S. , and Wolk, C. P. (2006) Signal transduction genes required for heterocyst maturation in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 188: 6688–6693.

Fay, P. (1969) Cellular differentiation and pigment composition in *Anabaena cylindrica*. *Arch Microbiol* 67: 62–70.

Fay, P. (1973) The heterocyst. In: Carr, N. G. , and Whitton, B. A. (Eds.) *The Biology of Blue-green Algae*. Blackwell Scientific Publications, Oxford, UK pp. 238–259.

Fay, P. (1976) Factors influencing dark nitrogen fixation in a blue-green alga. *Appl Environ Microbiol* 31: 376–379.

Fay, P. , and Fogg, G. E. (1962) Studies on nitrogen fixation by blue-green algae. III. Growth and nitrogen fixation in *Chlorogloea fritschii* Mitra. *Arch Microbiol* 42: 310–321.

Fay, P. , and Kulasooriya, S. A. (1972) Tetrazolium reduction and nitrogenase activity in heterocystous blue-green algae. *Arch Microbiol* 87: 341–352.

Fay, P. , and Lang, N. J. (1971) The heterocysts of blue-green algae. I. Ultrastructural integrity after isolation. *Proc R Soc B London* 178: 185–192.

Fay, P. , and Walsby, A. E. (1966) Metabolic activities of isolated heterocysts of the blue-green alga *Anabaena cylindrica*. *Nature (London)* 209: 94–95.

Fay, P. , Kumar, H. D. , and Fogg, G. E. (1964) Cellular factors affecting nitrogen fixation in the blue-green alga *Chlorogloea fritschii*. *J Gen Microbiol* 35: 351–360.

Fay, P. , Stewart, W. D. P. , Walsby, A. E. , and Fogg, G. E. (1968) Is the heterocyst the site of nitrogen fixation in blue-green algae? *Nature (London)* 220: 810–812.

Fernandez-Pinas, F. , Leganes, F. , and Wolk, C. P. (1994) A third genetic locus required for the formation of heterocysts in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 176: 5277–5283.

Ferreira, D. , Leitão, E. , Sjöholm, J. , Oliveira, P. , Lindblad, P. , Moradas-Ferreira, P. and Tamagnini, P. (2007) Transcription and regulation of the hydrogenase(s) accessory genes, *hypFCDEAB*, in the cyanobacterium *Lyngbya majuscula* CCAP 1446/4. *Arch Microbiol* 188: 609–617.

Fiedler, G. , Arnold, M. , Hannus, S. , and Maldener, I. (1998) The *devBCA* exporter is essential for envelope formation in heterocysts of the cyanobacterium *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 27: 1193–1202.

Fiedler, G. , Arnold, M. , Hannus, S. , and Maldener, I. (1999) An ABC exporter is essential for the localisation of envelope material in heterocysts of cyanobacteria. In: Peschek, G. A. , Loeffelhardt, W. , and Schmetterer, G. (Eds.) *The Phototrophic Prokaryotes*. Plenum Publishing Corporation, New York, N.Y. USA pp. 529–537.

Fiedler, G. , Muro-Pastor, A. M. , Flores, E. , and Maldener, I. (2001) NtcA-dependent expression of the *devBCA* operon, encoding a heterocyst-specific ATP-binding cassette transporter in *Anabaena* sp. *J Bacteriol* 183: 3795–3799.

Fieulaine, S. , Lunn, J. E. , Borel, F. , and Ferrer, J.-L. (2005) The structure of a cyanobacterial sucrose-phosphate reveals two sugar tongs that release free sucrose in the cell. *Plant Cell* 17: 2049–2058.

Fisher, R. , Tuli, R. , and Haselkorn, R. (1981) A cloned cyanobacterial gene for glutamine synthetase functions in *Escherichia coli*, but the enzyme is not adenylated. *Proc Natl Acad Sci USA* 78: 3393–3397.

Fleming, H. , and Haselkorn, R. (1973) Differentiation in *Nostoc muscorum*. Nitrogenase is synthesized in heterocysts. *Proc Natl Acad Sci USA* 70: 2727–2731.

Fleming, H. , and Haselkorn, R. (1974) The program of protein synthesis during heterocyst differentiation in nitrogen-fixing blue-green algae. *Cell* 3: 159–170.

Flores, E. , and Herrero, A. (2010) Compartmentalized function through cell differentiation in filamentous cyanobacteria. *Nat Rev Microbiol* 8: 39–50.

Flores, E. , and Muro-Pastor, M. I. (1988) Uptake of glutamine and glutamate by the dinitrogen fixing cyanobacterium *Anabaena* sp. PCC 7120. *FEMS Microbiol Lett* 56: 127–130.

Flores, E. , Pernil, R. , Muro-Pastor, A. M. , Mariscal, V. , Maldener, I. , Lechno-Yossef, S. , Fan, Q. , Wolk, C. P. , and Herrero, A. (2007) Septum localized protein required for filament integrity and diazotrophy in the heterocyst-forming cyanobacteria. *J Bacteriol* 189: 3884–3890.

Fogg, G. E. (1942) Studies on nitrogen fixation by blue-green algae. I. Nitrogen fixation by *Anabaena cylindrica* Lemm. *J Exp Biol* 19: 78–87.

Fogg, G. E. (1944) Growth and heterocyst production in *Anabaena cylindrica* Lemm. *New Phytol* 43: 164–175.

Fogg, G. E. (1949) Growth and heterocyst production in *Anabaena cylindrica* Lemm. II. In relation to carbon and nitrogen metabolism. *Ann Bot* 13: 240–259.

Fogg, G. E. (1951) Growth and heterocyst production in *Anabaena cylindrica* Lemm. III. The cytology of heterocysts. *Ann Bot* 15: 23–35.

Forchhammer, K. , and Tandeau de Marsac, N. (1994) The PII protein in the cyanobacterium *Synechococcus* sp. strain PCC 7942 is modified by serine phosphorylation and signals the cellular N-status. *J Bacteriol* 176: 84–91.

Forchhammer, K. , and Tandeau de Marsac, N. (1995) Phosphorylation of the PII protein (*glnB* gene product) in the cyanobacterium *Synechococcus* sp. strain PCC 7942: Analysis of the in vitro kinase activity. *J Bacteriol* 177: 5812–5817.

Forsberg, A. J. , Pavitt, G. D. , and Higgins, C. F. (1994) Use of transcriptional fusions to monitor gene expression: A cautionary tale. *J Bacteriol* 176: 2128–2132.

Fredriksson, C. , and Bergman, B. (1995) Nitrogenase varies diurnally in a subset of cells within colonies of the non-heterocystous cyanobacteria *Trichodesmium* spp. *Microbiology* 141: 2471–2478.

Franché, C. , and Cohen-Bazire, G. (1985) The structural *nif* genes of four symbiotic *Anabaena azollae* show a highly conserved physical arrangement. *Plant Sci* 39: 125–131.

Franché, C. , and Cohen-Bazire, G. (1987) Evolutionary divergence in the *nifK*, *D*, *H* gene region among nine symbiotic *Anabaena azollae* and between *Anabaena azollae* and some free-living heterocystous cyanobacteria. *Symbiosis* 3: 159–178.

Frías, J. E. , Flores, E. , and Herrero, A. (1994) Requirement of the regulatory protein NtcA for the expression of nitrogen assimilation and heterocyst development genes in the cyanobacterium *Anabaena* sp. PCC 7120. *Mol Microbiol* 14: 823–832.

Frías, J. E. , Flores, E. , and Herrero, A. (1997) Nitrate assimilation gene cluster from the heterocyst forming cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 179: 477–486.

Frías, J. E. , Mérida, A. , Herrero, A. , Martín-Nieto, J. , and Flores, E. (1993) General distribution of the nitrogen control gene *ntcA* in cyanobacteria. *J Bacteriol* 175: 5710–5713.

Fritsch, F. E. (1940) Some points in the structure of an *Anabaena*. *New Phytol* 3: 85–96.

Fritsch, F. E. (1945) The Structure and Reproduction of the Algae. Vol. II. Cambridge University Press, Cambridge, UK pp. 796–800.

Fritsch, F. E. (1951) The Heterocyst: A botanical enigma. *Proc Linn Soc London* 162: 194–211.

Fujita, Y. , Takagi, H. , and Hase, T. (1996) Identification of the *chlB* gene and the gene product essential for light-independent chlorophyll biosynthesis in the cyanobacterium *Plectonema boryanum*. *Plant Cell Physiol* 37: 313–323.

Gallon, J. R. , and Falah Hamidi, A. (1984) Studies on the effects of oxygen on acetylene reduction (nitrogen fixation) in *Gloeotheca* sp. ATCC 27152 *J Gen Microbiol* 130: 495–503.

Galmozzi, C. V. , Saelices, L. , Florencio, F. J. , and Muro-Pastor, M. I. (2010) Post-transcriptional regulation of glutamine synthetase in the filamentous cyanobacterium *Anabaena* sp. strain PCC 7120: Differential expression between vegetative cells and heterocysts. *J Bacteriol* 192: 4701–4711.

Gambacorta, A. , Pagnotta, E. , Romano, I. , Sodano, G. , and Trincone, A. (1998) Heterocyst glycolipids from nitrogen fixing cyanobacteria other than Nostocaceae. *Phytochemistry* 48: 801–805.

García-Domínguez, M. , Reyes, J. C. , and Florencio, F. J. (1999) Glutamine synthetase inactivation by protein-protein interaction. *Proc Natl Acad Sci USA* 96: 7161–7166.

García-Domínguez, M. , Reyes, J. C. , and Florencio, F. J. (2000) NtcA represses transcription of *glnA* and *glnB*, genes that encode inhibitors of glutamine synthetase type 1 from *Synechocystis* sp. strain PCC 6803. *Mol Microbiol* 35: 1192–1201.

Gerdtsen, Z. P. , Salgado, J. C. , Osses, A. , Asenjo, J. A. , Rapaport, I. , and Andrews, B. (2009) Modeling heterocyst pattern formation in cyanobacteria. *BMC Bioinformatics* 10: S16. doi:10.1186/1471-2105-10-S6-S16.

Ghassemian, M. , Wong, B. , Ferreira, F. , Markley, J. L. , and Straus, N. A. (1994) Cloning, sequencing and transcriptional studies of the genes for cytochrome *c-553* and plastocyanin from *Anabaena* sp. PCC 7120. *Microbiology* 140: 1151–1159.

Giddings, T. H. , and Staehelin, L. A. (1978) Plasma membrane architecture of *Anabaena cylindrica*: occurrence of microplasmodesmata and changes associated with heterocyst development and the cell cycle. *Cytobiologie* 16: 236–249.

Ginsberg, R. , and Lazaroff, N. (1973) Ultrastructural development of *Nostoc muscorum*. *J Gen Microbiol* 75: 1–9.

Golden, J. W. , and Wiest, D. R. (1988) Genome rearrangement and nitrogen fixation in *Anabaena* blocked by inactivation of *xisA* gene. *Science* 242: 1421–1423.

Golden, J. W. , and Yoon, H. S. (2003) Heterocyst development in *Anabaena*. *Curr Opin Microbiol* 6: 557–563.

Golden, J. W. , Carrasco, C. D. , Mulligan, M. E. , Schneider, G. J. , and Haselkorn, R. (1988) Deletion of a 55-kilobase-pair DNA element from the chromosome during heterocyst differentiation of *Anabaena* sp. strain PCC 7120. *J Bacteriol* 170: 5034–5041.

Golden, J. W. , Mulligan, M. E. , and Haselkorn, R. (1987) Different recombination site specificity of two developmentally regulated genome rearrangements. *Nature (London)* 327: 526–529.

Golden, J. W. , Robinson, S. J. , and Haselkorn, R. (1985) Rearrangement of nitrogen fixation genes during heterocyst differentiation in the cyanobacterium *Anabaena*. *Nature (London)* 314: 419–423.

Golden, J. W. , Whorff, L. L. , and Wiest, D. R. (1991) Independent regulation of *nifHDK* operon transcription and DNA rearrangement during heterocyst differentiation in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 173: 7098–7105.

Golden, S. S. , Brusslan, J. , and Haselkorn, R. (1987) Genetic engineering of the cyanobacterial chromosome. *Methods Enzymol* 153: 215–231.

Gonzalez, L. , Phalip, V. , and Zhang, C.-C. (2001) Characterization of PknC, a Ser/Thr kinase with broad substrate specificity from the cyanobacterium *Anabaena* sp. strain PCC 7120. *Eur J Biochem* 268: 1869–1875.

Gotto, J. W. , Tabita, F. R. , and Van Baalen, C. (1979) Mutants of *Anabaena* strain CA altered in their ability to grow under nitrogen-fixing conditions. *J Bacteriol* 140: 327–332.

Govezensky, D. , Greener, T. , Segal, G. , and Zamir, A. (1991) Involvement of GroEL in *nif* gene regulation and nitrogenase assembly. *J Bacteriol* 173: 6339–6346.

Grillo, J. F. , Bottomley, P. J. , Van Baalen, C. , and Tabita, F. R. (1979) A mutant of *Anabaena* sp. CA with oxygen-sensitive nitrogenase activity. *Biochem Biophys Res Commun* 89: 685–693.

Gupta, M. , and Carr, N. G. (1981a) Detection of glutamate synthase in heterocysts of *Anabaena*. *J Bacteriol* 148: 980–982.

Gupta, M. , and Carr, N. G. (1981b) Enzymology of arginine metabolism in heterocyst-forming cyanobacteria. *FEMS Microbiol Lett* 12: 179–181.

Hagedorn, H. (1960) Elektronenmikroskopische Untersuchungen an Blaualgen. *Naturwissenschaften* 47: 430.

Hagen, K. D. , and Meeks, J. H. (1999) Biochemical and genetic evidence for participation of DevR in a phosphorelay signal transduction pathway essential for heterocyst maturation in *Nostoc punctiforme* ATCC 29133. *J Bacteriol* 181: 4430–4434.

Hai, T. , Oppermann-Sanio, F. B. , and Steinbüchel, A. (1999) Purification and characterization of cyanophycin synthetase from the thermophilic *Synechococcus* sp. strain MA19. *FEMS Microbiol Lett* 181: 229–236.

Hai, T. , Oppermann-Sanio, F. B. , and Steinbüchel, A. (2002) Molecular characterization of a thermostable cyanophycin synthetase from the thermophilic cyanobacterium *Synechococcus* sp. strain MA19 and in vitro synthesis of cyanophycin and related polyamines. *Appl Environ Microbiol* 68: 93–101. doi:10.1128/AEM.68.1.93-101.2002

Hallenbeck, P. C. , and Benemann, J. R. (1978) Characterization and partial purification of the reversible hydrogenase of *Anabaena cylindrica*. *FEBS Lett* 94: 261–264.

Happe, T. , Schütz, K. , and Böhme, H. (2000) Transcriptional and mutational analysis of the uptake hydrogenase of the filamentous cyanobacterium *Anabaena variabilis* ATCC 29413. *J Bacteriol* 182: 1624–1631.

Hauray, S. F. , and Wolk, C. P. (1978) Classes of *Anabaena* mutants with oxygen-sensitive nitrogenase activity. *J Bacteriol* 136: 688–692.

Herrero, A. , and Wolk, C. P. (1986) Genetic mapping of the chromosome of the cyanobacterium, *Anabaena variabilis*. *J Biol Chem* 261: 7748–7754.

Häfele, U. , Scherer, S. , and Böger, P. (1988) Cytochrome *aa3* from heterocysts of the cyanobacterium *Anabaena variabilis*: Isolation and spectral characterization. *Biochim Biophys Acta* 934: 186–190.

Häger, K. P., Danneberg, G., and Böthe, H. (1983) The glutamate synthase in heterocysts of *Nostoc muscorum*. *FEMS Microbiol Lett* 17: 179–183.

Hansel, A., Axelsson, R., Lindberg, P., Troshina, O. Y., Wüschiers, R., and Lindblad, P. (2001) Cloning and characterisation of a hyp gene cluster in the filamentous cyanobacterium *Nostoc* sp. strain PCC 73102. *FEMS Microbiol Lett* 201: 59–64.

Haselkorn, R. (1978) Heterocysts. *Annu Rev Plant Physiol* 29: 319–344.

Haselkorn, R. (1992) Developmentally regulated gene rearrangements in prokaryotes. *Annu Rev Genet* 26: 113–130.

Haselkorn, R. (2008) Cell-cell communication in filamentous cyanobacteria. *Mol Microbiol* 70: 783–785.

Haselkorn, R. (2010) A new player in the regulatory cascade controlling heterocyst differentiation. *Mol Microbiol* 77: 537–539.

Haselkorn, R., Golden, J. W., Lammers, P. J., and Mulligan, M. E. (1986) Developmental rearrangement of cyanobacterial nitrogen fixation genes; *Trends Genet* 2: 255–259.

Haselkorn, R., Rice, D., Curtis, S. E., and Robinson, S. J. (1983) Organization and transcription of genes important in *Anabaena* heterocyst differentiation. *Ann Microbiol (Inst. Pasteur)* 134B: 181–193.

Haury, J. F., and Spiller, H. (1981) Fructose uptake and influence on growth of and nitrogen fixation by *Anabaena variabilis*. *J Bacteriol* 147: 227–235.

Hausinger, R. P. (1987) Nickel utilization by microorganisms. *Microbiol Rev* 51: 22–42.

Hawkesford, M. J., Houchins, J. P., and Hind, G. (1983) Reconstitution of photosynthetic electron transfer in cyanobacterial heterocyst membranes. *FEBS Lett* 159: 262–266.

Haystead, A., Robinson, R., and Stewart, W. D. P. (1970) Nitrogenase activity in extracts of heterocystous and non-heterocystous blue-green algae. *Arch Microbiol* 74: 235–243.

Hebbar, P. B., and Curtis, S. E. (2000) Characterization of devH, a gene encoding a putative DNA binding protein required for heterocyst function in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 182: 3572–3581.

Henson, B. J., Watson, L. E., and Barnum, S. R. (2005) Characterization of a 4 kb variant of the nifD element in *Anabaena* sp. strain ATCC 33047. *Curr Microbiol* 50: 129–132.

Henson, B. J., Pennigton, L. E., Watson, L. E., and Barnum, S. R. (2008) Excision of the nifD element in the heterocystous cyanobacteria. *Arch Microbiol* 189: 357–366.

Herrero, A., and Flores, E. (1990) Transport of basic amino acids by the dinitrogen-fixing cyanobacterium *Anabaena* PCC 7120. *J Biol Chem* 265: 3931–3935.

Herrero, A., Muro-Pastor, A. M., and Flores, E. (2001) Nitrogen control in cyanobacteria. *J Bacteriol* 183: 411–425.

Higa, K. C., and Callahan, S. M. (2010) Ectopic expression of hetP can partially bypass the need for hetR in heterocyst differentiation by *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 77: 562–574.

Hoffmann, D., Gutekunst, K., Klissenbauer, M., Schluz-Friedrich, R., and Appel, J. (2006) Mutagenesis of hydrogenase accessory genes of *Synechocystis* sp. PCC 6803. Additional homologues of hypA and hypB are not active in hydrogenase maturation. *Febs J* 273: 4516–4527.

Holland, D., and Wolk, C. P. (1990) Identification and characterization of hetA, a gene that acts early in the process of morphological differentiation of heterocysts. *J Bacteriol* 172: 3131–3137.

Holmqvist, M., Stensjö, K., Oleviera, P., Lindberg, P., and Lindblad, P. (2009) Characterization of hupSL promoter activity in *Nostoc punctiforme* ATCC 29133. *BMC Microbiol* 9: 54 doi: 10.1186/1471-2180-9-54.

Houchins, J. P. (1984) The physiology and biochemistry of hydrogen metabolism in cyanobacteria. *Biochim Biophys Acta* 768: 227–255.

Houchins, J. P. (1985) Electron transfer chains of cyanobacterial heterocysts. In: Ludden, P. W., and Burris, J. E. (Eds.) *Nitrogen Fixation and CO₂ Metabolism*. Elsevier Science Publishers, Amsterdam, The Netherlands. pp. 261–268.

Houchins, J. P., and Burris, R. H. (1981a) Light and dark reactions of the uptake hydrogenase in *Anabaena* 7120. *Plant Physiol* 68: 712–716.

Houchins, J. P., and Burris, R. H. (1981b) Physiological reactions of the reversible hydrogenase from *Anabaena* 7120. *Plant Physiol* 68: 717–721.

Houchins, J. P., and Burris, R. H. (1981c) Occurrence and localization of two distinct hydrogenases in the cyanobacterium *Anabaena* sp. strain 7120. *J Bacteriol* 146: 209–214.

Houchins, J. P., and Hind, G. (1983) Flash spectroscopic characterization of photosynthetic electron transport in isolated heterocysts. *Arch Biochem Biophys* 225: 138–145.

Houchins, J. P., and Hind, G. (1984) Concentration and function of membrane-bound cytochromes in cyanobacterial heterocysts. *Plant Physiol* 76: 456–460.

Howarth, D. C., and Codd, G. A. (1985) The uptake and production of molecular hydrogen by unicellular cyanobacteria. *J Gen Microbiol* 131: 1561–1569.

Huang, G., Fan, Q., Lechno-Yossef, S., Wojciuch, E., Wolk, C. P., Kaneko, T., and Tabata, S. (2005) Clustered genes required for the synthesis of heterocyst envelope polysaccharide in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 187: 1114–1123.

Huang, X., Dong, Y., and Zhao, J. (2004) HetR homodimer is a DNA-binding protein required for heterocyst differentiation, and the DNA-binding activity is inhibited by PatS. *Proc Natl Acad Sci USA* 101: 4848–4853.

Imashimizu, M., Yoshimura, H., Katoh, H., Ehira, S., and Ohmori, M. (2005) NaCl enhances cellular cAMP and upregulation of genes related to heterocyst development in the cyanobacterium *Anabaena* sp. strain PCC 7120. *FEMS Microbiol Lett* 252: 97–103.

Ionescu, D., Voss, B., Oren, A., Hess, W. R., and Muro-Pastor, A. M. (2010) Heterocyst-specific transcription of NsiR1, a non-coding RNA encoded in a tandem array of direct repeats in cyanobacteria. *J Mol Biol* 398: 177–188.

Irmiler, A., Sanner, S., Dierks, H., and Forchhammer, K. (1997) Dephosphorylation of the phosphoprotein PII in *Synechococcus* PCC 7942: Identification of an ATP and 2-oxoglutarate-regulated phosphatase activity. *Mol Microbiol* 26: 81–90.

Iyengar, M. O. P., and Desikachary, T. V. (1953) Occurrence of three-pored heterocysts in *Brachytrichia balani* (Lloyd) Born. *Flah. Curr Sci* 22: 180–181.

Jacobson, B. L., Chae, Y. K., Markley, J. L., Rayment, I., and Holden, H. M. (1993) Molecular structure of the oxidized, recombinant heterocyst [2Fe-2S] ferredoxin from *Anabaena* 7120 determined to 1.7 Å resolution. *Biochemistry* 32: 6788–6793.

Jäger, K. M., and Bergman, B. (1990) Localization of a multifunctional chaperonin (GroEL protein) in nitrogen fixing *Anabaena* PCC 7120. Presence in vegetative cells and heterocysts. *Planta* 183: 120–125.

Jang, J., Shi, L., Tan, H., Janicki, A., and Zhang, C.-C. (2009) Mutual regulation of ntcA and hetR during heterocyst differentiation requires two similar PP2C-type protein phosphatases, PrpJ1 and PrpJ2, in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 191: 6059–6066.

Jang, J. , Wang, L. , Jeanjean, R. , and Zhang, C. C. (2007) PrpJ, a PP2C-type protein phosphatase located on the plasma membrane, is involved in heterocyst maturation in the cyanobacterium *Anabaena* sp. PCC 7120. *Mol Microbiol* 64: 347–358.

Janson, S. , Matveyev, A. , and Bergman, B. (1998) The presence and expression of *hetR* in the non-heterocystous cyanobacterium *Symploca* PCC 8002. *FEMS Microbiol Lett* 168: 173–179.

Jensen, B. B. , and Cox, R. P. (1983) Effect of oxygen concentration on dark nitrogen fixation and respiration in cyanobacteria. *Arch Microbiol* 135: 287–292.

Jensen, B. B. , Cox, R. P. , and Burris, R. H. (1986) Isolation of cyanobacterial heterocysts with high and sustained dinitrogen- fixation capacity supported by endogenous reductants. *Arch Microbiol* 145: 241–247.

Jiang, F. , Mannervik, B. , and Bergman, B. (1997) Evidence for redox regulation of the transcription factor NtcA, acting both as an activator and a repressor, in the cyanobacterium *Anabaena* PCC 7120. *Biochem J* 327: 513–517.

Jones, K. M. , and Haselkorn, R. (2002) Newly identified cytochrome c oxidase operon in the nitrogen-fixing cyanobacterium *Anabaena* sp. strain PCC 7120 specifically induced in heterocysts. *J Bacteriol* 184: 2491–2499.

Jones, K. M. , Buikema, W. J. , and Haselkorn, R. (2003) Heterocyst-specific expression of *patB*, a gene required for nitrogen fixation in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 185: 2306–2314.

Jüttner, F. (1983) ¹⁴C-labeled metabolites in heterocysts and vegetative cells of *Anabaena cylindrica* filaments and their presumptive function as transport vehicles of organic carbon and nitrogen. *J Bacteriol* 155: 628–633.

Kale, S. R. (1972) Effect of light on the development of heterocysts in *Anabaena ambigua* Rao. In: Desikachary, T. V. . (Ed.) *The Biology of Blue-green Algae*. University of Madras, Madras pp. 203–208.

Kale, S. R. , and Talpasayi, E. R. S. (1969) Heterocysts: A review. *Indian Biologist* 1: 19–29.

Kallas, T. , Coursin, T. , and Rippka, R. (1985) Different organization of *nif* genes in non-heterocystous and heterocystous cyanobacteria. *Plant Mol Biol* 5: 321–329.

Kallas, T. , Spiller, S. , and Malkin, R. (1988) Primary structure of cotranscribed genes encoding the Rieske Fe-S and cytochrome f proteins of the cyanobacterium *Nostoc* PCC 7906. *Proc Natl Acad Sci USA* 85: 5794–5798.

Kaneko, T. , Sato, S. , Kotani, H. , Tanaka, A. , Asamizu, E. , Nakamura, Y. , Miyajima, N. , Hirose, M. , Sugiura, M. , Sakamoto, S. , Kimura, T. , Hosouchi, T. , Matsuno, A. , Muraki, A. , Nakazaki, A. , Naruo, K. , Okumura, S. , Shimpo, S. , Takeuchi, C. , Wada, T. , Watanabe, A. , Yamada, M. , Yasuda, M. , and Tabata, S. (1996) Sequence analysis of the genome of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. II. Sequence determination of the entire genome and assignment of potential protein-coding regions. *DNA Res* 3: 109–136.

Kaneko, T. , Nakamura, Y. , Wolk, C. P. , Kuritz, T. , Sasamoto, S. , Watanabe, A. , Iriguchi, M. , Ishikawa, A. , Kawashima, K. , Kimura, T. , Kishida, Y. , Kohara, M. , Matsumoto, M. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Shimpo, S. , Sugimoto, M. , Takazawa, M. , Yamada, M. , Yasuda, M. , and Tabata, S. (2001) Complete genomic sequence of the filamentous nitrogen- fixing cyanobacterium *Anabaena* sp. strain PCC 7120. *DNA Res* 8: 205–213.

Kaplan, D. , and Peters, G. A. (1981) The *Azolla*-*Anabaena* relationship X.15 N₂ fixation and transport in main stem axes. *New Phytol* 89: 337–346.

Kaplan, D. , Calvert, H. E. , and Peters, G. A. (1986) The *Azolla*-*Anabaena* relationship. XII. Nitrogenase activity and phycobiliproteins of the endophyte as a function of leaf age and cell type. *Plant Physiol* 80: 884–890.

Kangatharalingam, N. , Priscu, J. C. , and Paerl, H. W. (1992) Heterocyst envelope thickness, heterocyst frequency and nitrogenase activity in *Anabaena flos-aquae*: Influence of exogenous oxygen tension. *J Gen Microbiol* 138: 2673–2678.

Karradt, A. , Sobanski, J. , Mattow, J. , Lockau, W. , and Baier, K. (2008) NblA, a key protein of phycobilisome degradation interacts with ClpC, a HSP100 chaperone partner of a cyanobacterial Clp protease. *J Biol Chem* 283: 32394–32403.

Kaushik, M. , and Kumar, H. D. (1970) The effect of light on growth and development of two blue-green algae. *Arch Microbiol* 74: 52–57.

Ke, B. , Fang, Z. X. , Lu, R. Z. , Calvert, H. E. , and Dolan, E. (1983) The presence of phycobilisomes in heterocysts of *Anabaena variabilis*. *Photobiochem Photobiophys* 6: 25–31.

Khudyakov, I. , and Wolk, C. P. (1997) *hetC*, a gene coding for a protein similar to bacterial ABC protein exporters, is involved in early regulation of heterocyst differentiation. *J Bacteriol* 179: 6971–6978.

Khudyakov, I. Y. , and Golden, J. W. (2001) Identification and inactivation of three group 2 sigma factor genes in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 183: 6667–6675.

Khudyakov, I. Y. , and Golden, J. W. (2004) Different functions of *HetR*, the master regulator of heterocyst differentiation in *Anabaena* sp. PCC 7120, can be separated by mutation. *Proc Natl Acad Sci USA* 101: 16040–16045.

Khudyakov, I. Y. , and Pinevich, A. V. (1992) Unicellular mutant of the filamentous cyanobacterium *Anabaena* sp. PCC 7118. *Mikrobiologiya* 60: 704–708.

Kerson, G. W. , Miernyk, J. A. , and Budd, K. (1984). Evidence for the occurrence of, and possible physiological role for, cyanobacterial calmodulin. *Plant Physiol* 75: 222–224.

Kneip, C. , Lockhart, P. , Voß, C. , and Maier, U. G. (2007) Nitrogen fixation in eukaryotes. New models for symbiosis. *Evol Biol* 7: 55. doi:10.1186/1471-2148/7/55

Koksharova, O. A. , and Wolk, C.P. (2002) A novel gene that bears a DnaJ motif influences cyanobacterial cell division. *J Bacteriol* 184: 5524–5528.

Kolodny, N. H. , Bauer, D. , Bryce, K. , Klucsevsek, K. , Lane, A. , Medeiros, L. , Mercer, W. , Moin, S. , Park, D. , Petersen, J. , Wright, J. , Yuen, C. , Wolfson, A. J. , and Allen, M. M. (2006) Effect of nitrogen source on cyanophycin synthesis in *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 188: 934–940.

Krepski, W. J. , and Wolk, C. P. (1983) Biosynthesis of the envelope glycolipids during heterocyst development in *Anabaena cylindrica*. *J Gen Microbiol* 129: 105–110.

Kuhn, I. , Peng, L. , Bedu, S. , and Zhang, C.-C. (2000) Developmental regulation of the cell division protein FtsZ in *Anabaena* sp. strain PCC 7120, a cyanobacterium capable of terminal differentiation. *J Bacteriol* 182: 4640–4643.

Kulasooriya, S. A. , Lang, N. , and Fay, P. (1972) The heterocysts of blue-green algae. III. Differentiation and nitrogenase activity. *Proc R Soc B London* 181: 199–209.

Kumar, A. , and Kumar, H. D. (1980) Differential effects of amino acid analogs on growth and heterocyst differentiation in two nitrogen fixing blue-green algae. *Curr Microbiol* 3: 213–218.

Kumar, A. , Tabita, F. , and Van Baalen, C. (1982) Isolation and characterization of heterocysts from *Anabaena* sp. strain CA. *Arch Microbiol* 133: 103–109.

Kumar, A. P. , Perraju, B. T. V. V. , and Singh, H. N. (1986) Carbon nutrition and regulation of uptake hydrogenase activity in free-living and symbiotic *Anabaena cycadae*. *New Phytol* 104: 115–120.

Kumar, A. P. , Rai, A. N. , and Singh, H. N. (1985) Nitrate reductase activity in isolated heterocysts of the cyanobacterium *Nostoc muscorum*. *FEBS Lett* 179: 125–128.

Kumar, D. , and Kumar, H. D. (1990) Effect of some inhibitors and carbon sources on acetylene reduction and hydrogen production of isolated heterocysts of *Anabaena* sp. (strain CA). *Eur J Phycol* 25: 375–379.

Kumar, H. D. , and Kaushik, M. (1971) Studies on growth and development of two nitrogen-fixing blue-green algae. *Zeitschrift Pflanzenphysiol* 65: 443–453.

Kumar, K. , Mella-Herrera, R. A. , and Golden, J. W. (2010) Cyanobacterial heterocysts. *Cold Spring Harb Perspect Biol* 2: a000315. Epub.

Kumar, S. , and Polasa, H. (1991) Influence of nickel and copper on photobiological hydrogen production and uptake in *Oscillatoria subbrevis* strain 111. *Proc Indian Nat Sci Acad* 57: 281–285.

Lahmi, R. , Sendersky, E. , Perelman, A. , Hagemann, M. , Forchhammer, K. , and Schwarz, R. (2006) Alanine dehydrogenase activity is required for adequate progression of phycobilisome degradation during nitrogen starvation in *Synechococcus elongatus* PCC 7942. *J Bacteriol* 188: 5258–5265.

Lambein, F. , and Wolk, C. P. (1973) Structural studies on the glycolipids from the envelope of the heterocyst of *Anabaena cylindrica*. *Biochemistry* 12: 791–798.

Lambert, G. R. , and Smith, G. D. (1981) The hydrogen metabolism of cyanobacteria (blue-green algae). *Biol Rev* 56: 589–660.

Lammers, P. J. , and Haselkorn, R. (1983) Sequence of the *nifD* gene coding for the α subunit of dinitrogenase from the cyanobacterium *Anabaena*. *Proc Natl Acad Sci USA* 80 4723–4727.

Lammers, P. J. , Golden, J. W. , and Haselkorn, R. (1986) Identification and sequence of a gene required for developmentally regulated DNA excision in *Anabaena*. *Cell* 44: 905–911.

Lang, N. J. (1965) Electron microscopic study of heterocyst development in *Anabaena azollae* Strasburger. *J Phycol* 1: 127–134.

Lang, N. J. (1968) The fine structure of blue-green algae. *Annu Rev Microbiol* 22: 15–46.

Lang, N. J. , and Fay, P. (1971) The heterocysts of blue-green algae. II. Details of ultrastructure. *Proc R Soc B London* 178: 193–203.

Lang, N. J. , Krupp, J. M. , and Koller, A. L. (1987) Morphological and ultrastructural changes in vegetative cells and heterocysts of *Anabaena variabilis* grown with fructose. *J Bacteriol* 169: 920–923.

Lang, N. J. , Simon, R. D. , and Wolk, C. P. (1972) Correspondence of cyanophycin granules with structured granules in *Anabaena cylindrica*. *Arch Microbiol* 83: 313–320.

Laurent, S. , Chen, H. , Bédu, S. , Ziarelli, F. , Peng, L. , and Zhang, C.-C. (2005) Nonmetabolizable analogue of 2-oxoglutarate elicits heterocyst differentiation under repressive conditions in *Anabaena* sp. PCC 7120. *Proc Natl Acad Sci USA* 102: 9907–9912.

Lawrie, A. C. , Codd, G. A. , and Stewart, W. D. P. (1976) The incorporation of nitrogen into products of recent photosynthesis in *Anabaena cylindrica* Lemm. *Arch Microbiol* 107: 15–24.

Lechno-Yossef, S. , Fan, Q. , Ehira, S. , Sato, N. , and Wolk, C. P. (2006) Mutations in four regulatory genes have interrelated effects on heterocyst maturation in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 188: 7387–7395.

Lee, H.-M. , Vazquez-Bermudez, M. F. , and Tandeau de Marsac, N. (1999) The global nitrogen regulator NtcA regulates transcription of the signal transducer PII (GlnB) and influences its phosphorylation level in response to nitrogen and carbon supplies in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 181: 2697–2702.

Leganés, F. , Fernandes-Pinas, F. , and Wolk, C. P. (1998) A transposon-induced mutant of *Nostoc ellipsosporum* implicates an arginine-biosynthetic gene in the formation of cyanophycin granules and of functional heterocysts and akinetes. *Microbiology* 144: 1799–1805.

Leitão, E. , Oxelfelt, F. , Oliveira, P. , Moradas-Ferreira, P. , and Tamagnini, P. (2005) Analysis of the *hupSL* operon of the nonheterocystous cyanobacterium *Lyngbya majuscula* CCAP 1446/4: Regulation of transcription and expression under a light-dark regime. *Appl Environ Microbiol* 71: 4567–4576.

Lex, M. , and Carr, N. G. (1974) The metabolism of glucose by heterocysts and vegetative cells of *Anabaena cylindrica*. *Arch Microbiol* 101: 161–167.

Li, B. , Huang, X. , and Zhao, J. (2002) Expression of *hetN* during heterocyst differentiation and its inhibition of *hetR* up- regulation in the cyanobacterium *Anabaena* sp. strain PCC 7120. *FEBS Lett* 517: 87–91.

Li, H. , Sherman, D. M. , Bao, S. , and Sherman, L. A. (2001) Pattern of cyanophycin accumulation in nitrogen-fixing and non- nitrogen-fixing cyanobacteria. *Arch Microbiol* 176: 9–18.

Li, J. H. , Laurent, S. , Konde, V. , Bédu, S. , and Zhang, C.-C. (2003) An increase in the level of 2-oxoglutarate promotes heterocyst development in the cyanobacterium *Anabaena* sp. strain PCC7120. *Microbiology* 149: 3257–3263. doi: 10.1099/mic.0.26462-0.

Liang, J. , Scappino, L. , and Haselkorn, R. (1992) The *patA* gene product, which contains a region similar to CheY of *Escherichia coli*, controls heterocyst pattern formation in the cyanobacterium *Anabaena* 7120. *Proc Natl Acad Sci USA* 89: 5655–5659.

Liang, J. , Scappino, L. , and Haselkorn, R. (1993) The *patB* gene product, required for growth of the cyanobacterium *Anabaena* sp. strain PCC 7120 under nitrogen-limiting conditions, contains ferredoxin and helix-turn-helix domains. *J Bacteriol* 175: 1697–1704.

Lindblad, P. , and Bergman, B. (1989) Occurrence and localization of phycoerythrin in symbiotic *Nostoc* of *Cycas revoluta* and in the free-living isolated *Nostoc* 7422. *Plant Physiol* 89: 783–785.

Lindblad, P. , and Sellstedt, A. (1990) Occurrence and localization of an uptake hydrogenase in the filamentous heterocystous cyanobacterium *Nostoc* PCC 73102. *Protoplasma* 159: 9–15.

Lindberg, P. , Hansel, A. , and Lindblad, P. (2000) *hupS* and *hupL* constitute a transcription unit in the cyanobacterium *Nostoc* sp. PCC 73102. *Arch Microbiol* 174: 129–133.

Linn, T. , and Pierre, R. St . (1990) Improved vector system for constructing transcriptional fusions that ensures independent translation of *lacZ*. *J Bacteriol* 172: 1077–1084.

Liu, D. , and Golden, J. W. (2002) *hetL* overexpression stimulates heterocyst formation in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 184: 6873–6881.

Liu, J. , and Chen, W.-L. (2009) Characterization of *HetN*, a protein involved in heterocyst differentiation in the cyanobacterium *Anabaena* sp. strain PCC 7120. *FEMS Microbiol Lett* 297: 17–23.

Llama, M. J. , Serra, J. L. , Rao, K. K. , and Hall, D. O. (1979) Isolation and characterization of the hydrogenase activity from the nonheterocystous cyanobacterium *Spirulina maxima*. *FEBS Lett* 98: 342–346.

Lockau, W. , Peterson, R. B. , Wolk, C. P. , and Burris, R. H. (1978) Modes of reduction of nitrogenase in heterocysts isolated from *Anabaena* species. *Biochim Biophys Acta* 502: 298–308.

Lopes Pinto, F. A. , Troshina, O. , and Lindblad, P. (2002) A brief look at three decades of research on cyanobacterial hydrogen evolution. *Internl J Hydrogen Energy* 27: 1209–1215.

López-Gomollón, S. , Hernández, J. A. , Wolk, C. P. , Peleato, M. L. , and Fillat, M. F. (2007) Expression of *furA* is modulated by *NtcA* and strongly enhanced in heterocysts of *Anabaena* sp. PCC 7120. *Microbiology* 153: 42–50.

López-Igual, R. , Flores, E. , and Herrero, A. (2010) Inactivation of a heterocyst-specific invertase indicates a principal role of sucrose catabolism in heterocysts of *Anabaena* sp. *J Bacteriol* 192: 5526–5533.

Ludwig, M. , Schulz-Friedrich, R. , and Appel, J. (2006) Occurrence of hydrogenases in cyanobacteria and anoxygenic photosynthetic bacteria: Implications for the phylogenetic origin of cyanobacterial and algal hydrogenases. *J Mol Evol* 63: 758–768.

Luque, I. , Flores, E. , and Herrero, A. (1994) Molecular mechanism for the operation of nitrogen control in cyanobacteria. *Embo J* 13: 2862–2869.

Luque, I. , Ochoa de Alda, J. A. G. , Richaud, C. , Zabulon, G. , Thomas, J.-C. , and Houmard, J. (2003) The NblA protein from the filamentous cyanobacterium *Tolypothrix* PCC 7601: Regulation of its expression and interactions with phycobilisome components. *Mol Microbiol* 50: 1043–1054.

Lunn, J. E. (2002) Evolution of sucrose synthesis. *Plant Physiol* 128: 1490–1500.

Lynn, M. E. , and Ownby, J. D. (1987) Transcriptional activity of heterocysts isolated from *Anabaena variabilis*. *Arch Microbiol* 148: 115–120.

Lynn, M. E. , Bantle, J. A. , and Ownby, J. D. (1986) Estimation of gene expression in heterocysts of *Anabaena variabilis* by using DNA-RNA hybridization. *J Bacteriol* 167: 940–946.

Lyons, F. M. , and Thiel, T. (1995) Characterization of *nifB*, *nifS* and *nifU* genes in the cyanobacterium *Anabaena variabilis*. *NifB* is required for the vanadium-dependent nitrogenase. *J Bacteriol* 177: 1570–1575.

Mackerras, A. H. , De Chazal, N. M. , and Smith, G. D. (1990) Transient accumulations of cyanophycin in *Anabaena cylindrica* and *Synechocystis* 6803. *J Gen Microbiol* 136: 2057–2065.

Makarova, K. S. , Koonin, E. V. , Haselkorn, R. , and Galperin, M. Y. (2006) Cyanobacterial response regulator PatA contains a conserved N-terminal domain (PATAN) with an alpha-helical insertion. *Bioinformatics* 22: 1297–1301.

Maldener, I. , Fiedler, G. , Ernst, A. , Fernández-Piñas, F. , and Wolk, C. P. (1994) Characterization of *devA*, a gene required for the maturation of proheterocysts in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 176: 7543–7549.

Maldener, I. , Hannus, S. , and Kammerer, M. (2003) Description of five mutants of the cyanobacterium *Anabaena* sp. strain PCC 7120 affected in heterocyst differentiation and identification of transposon-tagged genes. *FEMS Microbiol Lett* 224: 205–213.

Marcozzi, C. , Cumino, A. C. , and Salerno, G. L. (2009) Role of *NtcA*, a cyanobacterial global nitrogen regulator, in the regulation of sucrose metabolism gene expression in *Anabaena* sp. PCC 7120. *Arch Microbiol* 191: 255–263.

Mariscal, V. , Herrero, A. , and Flores, E. (2007) Continuous periplasm in a filamentous, heterocyst-forming cyanobacterium. *Mol Microbiol* 65: 1139–1145.

Mariscal, V. , Herrero, A. , Nenninger, A. , Mullineaux, C. W. , and Flores, E. (2011) Functional dissection of three domain SepJ protein joining the cells in cyanobacterial trichomes. *Mol Microbiol* 79: 1077–1088.

Marqués, S. , Florencio, F. J. , and Candau, P. (1992) Purification and characterization of the ferredoxin-glutamate synthase from the unicellular cyanobacterium *Synechococcus* sp. PCC 6301. *Eur J Biochem* 296: 69–77.

Martín-Figueroa, E. , Navarro, F. , and Florencio, F. J. (2000) The GS-GOGAT pathway is not operative in the heterocysts. Cloning and expression of *glisF* gene from the cyanobacterium *Anabaena* sp. PCC 7120. *FEBS Lett* 476: 282–286.

Masephol, B. , Schölisch, K. , Görlitz, K. , Kutzki, C. , and Böhme, H. (1997) The heterocyst-specific *fdxH* gene product of the cyanobacterium *Anabaena* sp. PCC 7120 is important but not essential for nitrogen fixation. *Mol Gen Genet* 253: 770–776.

Mazur, B. J. , and Chui, C.-F. (1982) Sequence of the gene coding for the β -subunit of dinitrogenase from the blue-green alga *Anabaena*. *Proc Natl Acad Sci USA* 79: 6782–6786.

Mazur, B. J. , Rice, D. , and Haselkorn, R. (1980) Identification of blue-green algal nitrogen fixation genes by using heterologous DNA hybridization probes. *Proc Natl Acad Sci USA* 77: 186–190.

Meeks, J. C. , Campbell, E. L. , Summers, M. L. , and Wong, F. C. (2002) Cellular differentiation in the cyanobacterium *Nostoc punctiforme*. *Arch Microbiol* 178: 395–403.

Meeks, J. C. , Joseph, C. M. , and Haselkorn, R. (1988) Organization of the *nif* genes in cyanobacteria in symbiotic association with *Azolla* and *Anthoceros*. *Arch Microbiol* 150: 61–71.

Meeks, J. C. , Elhai, J. , Thiel, T. , Potts, M. , Larimer, F. , Lamerdin, J. , Predki, P. , and Atlas, R. (2001) An overview of the genome of *Nostoc punctiforme*, a multicellular, symbiotic cyanobacterium. *Photosynth Res* 70: 85–106.

Meeks, J. C. , Wolk, C. P. , Lockau, W. , Schilling, N. , Shaffer, W. , and Chieu, W. S. (1978) Pathways of assimilation of $[13N]N_2$ and $13NH_4$ -by cyanobacteria with and without heterocysts. *J Bacteriol* 134: 125–130.

Meeks, J. C. , Wolk, C. P. , Thomas, J. , Lockau, W. , Shaffer, P. W. , Austin, S. M. , Chien, W.-S. , and Galonsky, A. (1977) The pathways of assimilation of $13NH_4^+$ by the cyanobacterium, *Anabaena cylindrica*. *J Biol Chem* 252: 7894–7900.

Melis, A. , and Happe, T. (2001) Hydrogen production: Green algae as a source of energy. *Plant Physiol* 127: 740–748.

Mella-Herrera, R. A. , Neunuebel, M. R. , and Golden, J. W. (2010) *Anabaena* sp. strain PCC 7120 *conR* contains a *LytR-CpsA*-Psr domain, is developmentally regulated, and is essential for diazotrophic growth and heterocyst morphogenesis. *Microbiology* 157: 617–626. doi:10.1099/mic.0.046128-0

Mérida, A. , Candau, P. , and Florencio, F. J. (1991) Regulation of glutamine synthetase activity in the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803 by the nitrogen source: Effect of ammonium. *J Bacteriol* 173: 4095–4100.

Merino-Puerto, V. , Mariscal, V. , Mullineaux, C. W. , Herrero, A. , and Flores, E. (2010) Fra proteins influencing filament integrity, diazotrophy and localization of septal protein SepJ in the heterocyst forming cyanobacterium *Anabaena* sp. *Mol Microbiol* 75: 1159–1170.

Metzner, I. (1955) Zur chemie und zum submikroskopischen aufbau der zellwainde, Scheiden und Gallerten von Cyanophyceen. *Arch Mikrobiol* 22: 45–77.

Mickelson, J. C. , Davis, E. B. , and Tischer, R. G. (1967) The effect of various nitrogen sources upon heterocyst formation in *Anabaena flos-aquae* A-37. *J Exp Bot* 18: 397–405.

Min, H. , and Sherman, L. A. (2010) Hydrogen production by the unicellular diazotrophic cyanobacterium *Cyanothece* sp. strain ATCC 51142 under continuous light. *Appl Environ Microbiol* 76: 4293–4301. doi: 10.1128/AEM.00146-10.

Mishra, A. K. , and Tiwari, D. N. (1986) Mutagenesis and isolation of morphological mutants impaired in nitrogen-fixing capacity from a cyanobacterium *Gloeotrichia ghosei*. *New Phytol* 103: 69–77.

Mitchison, G. J. , and Wilcox, M. (1972) Rule governing cell division in *Anabaena*. *Nature* (London) 239: 110–111.

Mitchison, G. J. , and Wilcox, M. (1973) Alteration in heterocyst pattern of *Anabaena* produced by 7-azatryptophan. *Nat New Biol* 246: 229–233.

Mitchison, G. J. , Wilcox, M. , and Smith, R. J. (1976) Measurement of an inhibitory zone. *Science* 191: 866–868.

Mitra, A. K. (1950) Two new algae from Indian soils. *Ann Bot* 14: 457–464.

Miyagishima, S.-y. , Wolk, C. P. , and Osteryoung, K. W. (2005) Identification of cyanobacterial cell division genes by comparative and mutational analyses. *Mol Microbiol* 56: 126–143.doi: 10.1111/j.1365-2958.2005.04548.x

Montesinos, M. L. , Herrero, A. , and Flores, E. (1995) Amino acid transport systems required for diazotrophic growth in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 177: 3150–3157.

Montesinos, M. L. , Herrero, A. , and Flores, E. (1997) Amino acid transport in taxonomically diverse cyanobacteria and identification of two genes encoding elements of a neutral amino acid permease putatively involved in recapture of leaked hydrophobic amino acids. *J. Bacteriol.* 179: 853-862.

Moslavac, S. , Nicolaisen, K. , Mirus, O. , Dehni, F. A. , Pernil, R. , Flores, E. , Maldener, I. , and Schleiff, E. (2007) A TolC-like protein is required for heterocyst development in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 189: 7887–7895.

Mulligan, M. E. , and Haselkorn, R. (1989) Nitrogen fixation (nif) genes of the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Biol Chem* 264: 19200–19207.

Mullineaux, C. W. , Mariscal, V. , Nenninger, A. , Khanum, H. , Herrero, A. , Flores, E. , and Adams, D. G. (2008) Mechanism of intercellular molecular exchange in heterocyst-forming cyanobacteria. *Embo J* 27: 1299–1308.

Muro-Pastor, A. M. , Flores, E. , and Herrero, A. (2009) NtcA-regulated heterocyst differentiation genes *hetC* and *devB* from *Anabaena* sp. strain PCC 7120 exhibit a similar tandem promoter arrangement. *J Bacteriol* 191: 5765–5774.

Muro-Pastor, A. M. , Olmedo-Verd, F. , and Flores, E. (2006) All4312, NtcA-regulated two-component response regulator in *Anabaena* sp. strain PCC 7120. *FEMS Microbiol Lett* 256: 171–177.

Muro-Pastor, A. M. , Valladares, A. , Flores, E. , and Herrero, A. (1999) The *hetC* gene is a direct target of the NtcA transcriptional regulator in cyanobacterial heterocyst development. *J Bacteriol* 181: 6664–6669.

Muro-Pastor, A. M. , Valladares, A. , Flores, E. , and Herrero, A. (2002) Mutual dependence of the expression of the cell differentiation regulatory protein HetR and the global nitrogen-regulator NtcA during heterocyst development. *Mol Microbiol* 44: 1377–1385.

Muro-Pastor, M. I. , Reyes, J. C. , and Florencio, F. J. (2001) Cyanobacteria perceive nitrogen status by sensing intracellular 2-oxoglutarate levels. *J Biol Chem* 276: 38320–38328.

Muro-Pastor, M. I. , Reyes, J. C. , and Florencio, F. J. (2005) Ammonium assimilation in cyanobacteria. *Photosynth Res* 83: 135–150.

Murry, M. A. , and Wolk, C. P. (1989) Evidence that the barrier to the penetration of oxygen into heterocysts depends upon two layers of the cell envelope. *Arch Microbiol* 151: 469–474.

Murry, M. A. , Hallenbeck, P. C. , and Banemann, J. R. (1984) Immunochemical evidence that nitrogenase is restricted to heterocysts in *Anabaena cylindrica*. *Arch Microbiol* 137: 194–199.

Murry, M. A. , Olafsen, A. G. , and Banemann, J. R. (1981) Oxidation of diaminobenzidine in the heterocysts of *Anabaena cylindrica*. *Curr Microbiol* 6: 201–206.

Nakamura, Y. , Kaneko, T. , Sato, S. , Minuro, M. , Miyashita, H. , Tsuchiya, T. , Sasamoto, S. , Watanabe, A. , Kawashima, K. , Kishida, Y. , Kiyokawa, C. , Kohara, M. , Matsumoto, M. , Matsuno, A. , Nakazaki, N. , Shimpo, S. , Takeuchi, C. , Yamada, M. , and Tabata, S. (2003) Complete genome structure of *Gloeobacter violaceus* PCC 7421, a cyanobacterium that lacks thylakoids. *DNA Res* 10: 137–145.

Navarro, F. , Chávez, S. , Candau, P. , and Florencio, F. J. (1995) Existence of two ferredoxin-glutamate synthases in the cyanobacterium *Synechocystis* sp. PCC 6803: isolation and insertional inactivation of *gltB* and *gltS* genes. *Plant Mol Biol* 27: 753–767.

Nayar, A. S. , Yamamura, H. , Rajagopalan, R. , Risser, D. D. , and Callahan, S. M. (2007) FraG is necessary for filament integrity and heterocyst maturation in the cyanobacterium *Anabaena* sp. strain PCC 7120. *Microbiology* 153: 601–607. doi:10.1099/mic.0.2006/002535-0

Neilson, A. H. , and Larsson, T. (1980) The utilization of organic nitrogen for growth of algae: Physiological aspects. *Physiol Plant* 48: 542–553.

Neur, G. , and Bothe, H. (1982) The pyruvate-ferredoxin oxidoreductase in heterocysts of the cyanobacterium *Anabaena cylindrica*. *Biochim Biophys Acta* 716: 358–365.

Neur, G. , and Bothe, H. (1983) Anaplerotic reactions in *Anabaena cylindrica*. *FEBS Lett* 158: 79–83.

Neur, G. , and Bothe, H. (1985) Electron donation to nitrogenase. *Arch Microbiol* 143: 185–191.

Ni, S. , Benning, M. M. , Smola, M. J. , Feldmann, E. A. , and Kennedy, M. A. (2009) Crystal structure of Nupn_R1517, a putative negative regulator of heterocyst differentiation from *Nostoc punctiforme* PCC 73102. *Proteins* 74: 794–798. doi:10.1002/prot.22308

Nierzwicki-Bauer, S. A. , and Haselkorn, R. (1986) Differences in mRNA levels in *Anabaena* living freely or in symbiotic association with *Azolla*. *Embo J* 5: 29–35.

Nierzwicki-Bauer, S. A. , Balkwill, D. L. , Stevens, Jr., S. E. (1984a) Heterocyst differentiation in the cyanobacterium *Mastigocladus laminosus*. *J Bacteriol* 157: 514–525.

Nierzwicki-Bauer, S. A. , Balkwill, D. L. , Stevens, Jr., S. E. (1984b) A new method for identification of heterocysts and proheterocysts in morphologically complex cyanobacteria. *Biotechnic Histochem* 59: 163–170.

Ning, D. , and Xu, X. (2004a) *alr0117*, a two-component histidine kinase gene, is involved in heterocyst development in *Anabaena* sp. PCC 7120. *Microbiology* 150: 447–453.

Ning, D. , and Xu, X. (2004b) A novel region involved in heterocyst development and pattern formation in the genome of *Anabaena* sp. PCC 7120. *Shui Sheng Sheng Wu Xue Bao (Acta Hydrobiologica Sinica)* 28: 1–5 (in Chinese). Cited from Zhang et al. (2007).

Ochoa de Alda, J. A. G. , Lichtle, C. , Thomas, J. C. , and Houmard, J. C. (2004) Immunolocalization of NblA, a protein involved in phycobilisome turnover during heterocyst differentiation in cyanobacteria. *Microbiology* 150: 1377–1384. doi:10.1099/mic.0.26992-0

Ogawa, R. E. , and Carr, N. G. (1969) The influence of nitrogen on heterocyst production in blue-green algae. *Limnol Oceanogr* 14: 342–350.

Ohmori, M. , and Hattori, A. (1971) Nitrogen fixation and heterocysts in the blue-green alga *Anabaena cylindrica*. *Plant Cell Physiol* 12: 961–967.

Ohmori, M. , Ikeuchi, M. , Sato, N. , Wolk, C. P. , Kaneko, T. , Ogawa, T. , Kanehisa, M. , Goto, S. , Kawashima, S. , Okamoto, S. , Yoshimura, H. , Katoh, H. , Fujisawa, T. , Ehira, S. , Kamei, A. , Yoshihara, S. , Narikawa, R. , and Tabata, S. (2001) Characterization of genes encoding multi-domain proteins in the genome of the filamentous nitrogen-fixing cyanobacterium *Anabaena* sp. strain PCC 7120.

- Okuhara, H. , Matsumara, T. , Fujita, Y. , and Hase, T. (1999) Cloning and inactivation of genes encoding ferredoxin- and NADH-dependent glutamate synthase in the cyanobacterium *Plectonema boryanum*. Imbalances in nitrogen and carbon assimilations caused by deficiency of the ferredoxin-dependent enzyme. *Plant Physiol* 20: 33–41.
- Oliveira, P. , Leitão, E. , Tamagnini, P. , Moradas-Ferreira, P. , and Oxelfelt, F. (2004) Characterization and transcriptional analysis of hupSLW in *Gloeotheca* sp. ATCC 27152: An uptake hydrogenase from a unicellular cyanobacterium. *Microbiology* 150: 3647–3655.
- Olmedo-Verd, E. , Flores, E. , Herrero, A. , and Muro-Pastor, A. M. (2005) HetR-dependent and -independent expression of heterocyst related genes in an *Anabaena* strain overproducing the NtcA transcription factor. *J Bacteriol* 187: 1985–1991.
- Olmedo-Verd, E. , Muro-Pastor, A. M. , Flores, E. , and Herrero, A. (2006) Localized induction of ntcA regulatory gene in developing heterocysts of *Anabaena* sp. strain PCC 7120. *J Bacteriol* 188: 6694–6699.
- Olmedo-Verd, E. , Valladares, A. , Flores, E. , Herrero, A. , and Muro-Pastor, A. M. (2008) Role of two NtcA-binding sites in the complex ntcA gene promoter of the heterocyst-forming cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 190: 7584–7590.
- Onek, L. A. , and Smith, R. J. (1992) Calmodulin and calcium-mediated regulation in prokaryotes. *J Gen Microbiol* 138: 1039–1049.
- Onek, L. A. , Lea, P. J. , and Smith, R. J. (1992) Isolation and characterization of calmodulin-like protein from the cyanobacterium *Nostoc* sp. PCC 6720. *Arch Microbiol* 161: 352–358.
- Orozco, C. C. , Risser, D. D. , and Callahan, S. M. (2006) Epistasis analysis of four genes from *Anabaena* sp. strain PCC 7120 suggests a connection between PatA and PatS in heterocyst pattern formation. *J Bacteriol* 188: 1808–1816.
- Orr, J. , and Haselkorn, R. (1981) Kinetic and inhibition studies of glutamine synthetase from the cyanobacterium *Anabaena* 7120. *J Biol Chem* 256: 13099–13104.
- Orr, J. , and Haselkorn, R. (1982) Regulation of glutamine synthetase activity and synthesis in free-living and symbiotic *Anabaena* spp. *J Bacteriol* 152: 626–635.
- Osanai, T. , Ikeuchi, M. , and Tanaka, K. (2008) Group 2 sigma factors in cyanobacteria. *Plant Physiol* 133: 490–506.
- Osnai, T. , Kanesaki, T. , Nakano, T. , Takahashi, H. , Asayama, M. , Shirai, M. , Kanehisa, M. , Suzuki, I. , Murata, N. , and Tanaka, K. (2005) Positive regulation of sugar catabolic pathways in the cyanobacterium *Synechocystis* sp. PCC 6803 by the group 2 σ factor Sig E. *J Biol Chem* 280: 39653–39659. <http://www.jbc.org>
- Oxelfelt, F. , Tamagnini, P. , Salema, R. , and Lindblad, P. (1995) Hydrogen uptake in *Nostoc* strain PCC 73102: Effects of nickel, hydrogen, carbon and nitrogen. *Plant Physiol Biochem* 33: 617–623.
- Padhy, R. N. , and Singh, P. K. (1978) Genetical studies on the heterocyst and nitrogen fixation of the blue-green alga *Nostoc muscorum*. *Mol Gen Genet* 162: 203–211.
- Pandey, D. C. , and Mitra, A. K. (1962) Production of heterocysts in certain *Myxophyceae* as influenced by the concentration of nitrogen in the medium. *Naturwissenschaften* 49: 89–91.
- Pankratz, H. S. , and Bowen, C. C. (1963) Cytology of blue-green algae. I. The cells of *Symploca muscorum*. *Am J Bot* 50: 387–399.
- Papen, H. , Neur, G. , Refaian, M. , and Bothe, H. (1983) The isocitrate dehydrogenase from cyanobacteria. *Arch Microbiol* 134: 73–79.
- Papen, H. , Neur, G. , Sauer, A. , and Bothe, H. (1986) Properties of the glyceraldehyde-3-P dehydrogenase in heterocysts and vegetative cells of cyanobacteria. *FEMS Microbiol Lett* 36: 201–206.
- Parkinson, J. S. (1993) Signal transduction schemes of bacteria. *Cell* 73: 857–871.
- Paz-Yepes, J. , Flores, E. , and Herrero, A. (2003) Transcriptional effects of the signal transduction protein P(II) (glnB gene product) on NtcA-dependent genes in *Synechococcus* sp. PCC 7942. *FEBS Lett* 543: 42–46.
- Peat, A. , and Whitton, B. A. (1967) Environmental effects on the structure of the blue-green alga *Chlorogloea fritschii*. *Arch Microbiol* 57: 153–180.
- Pederson, D. M. , Daday, A. , and Smith, G. D. (1986) The use of nickel to probe the role of hydrogen metabolism in cyanobacterial nitrogen fixation. *Biochemie* 68: 113–120.
- Pernil, R. , Herrero, A. , and Flores, E. (2010) Catabolic function of compartmentalized alanine dehydrogenase in the heterocyst-forming cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 192: 5165–5172.
- Pernil, R. , Picossi, S. , Mariscal, V. , Herrero, A. , and Flores, E. (2008) ABC-type amino acid uptake transporter Bgt and N-II of *Anabaena* sp. strain PCC 7120 share an ATPase unit and are expressed in vegetative cells and heterocysts. *Mol Microbiol* 67: 1067–1080.
- Peschek, G. A. (1987) Respiratory electron transport. In: Fay, P. and Van Baalen, C. (Eds.) *The Cyanobacteria*. Elsevier Science Publishers, Amsterdam. The Netherlands. pp. 119–169.
- Peterson, R. B. , and Burris, R. H. (1976) Properties of heterocysts isolated with colloidal silica. *Arch Microbiol* 108: 35–40.
- Peterson, R. B. , and Burris, R. H. (1978) Hydrogen metabolism in isolated heterocysts of *Anabaena* 7120. *Arch Microbiol* 116: 125–132.
- Peterson, R. B. , and Wolk, C. P. (1978) High recovery of nitrogenase activity of ⁵⁵Fe-labeled nitrogenase in heterocysts isolated from *Anabaena variabilis*. *Proc Natl Acad Sci USA* 75: 6271–6275.
- Peterson, R. B. , Dolan, E. , Calvert, H. E. , and Ke, B. (1981) Energy transfer from phycobiliproteins to photosystem I in vegetative cells and heterocysts of *Anabaena variabilis*. *Biochem Biophys Acta* 634: 237–248.
- Pettersson, A. , and Bergman, B. (1989) Calmodulin in heterocystous cyanobacteria: Biochemical and immunological evidence. *FEMS Microbiol Lett* 60: 95–99.
- Picossi, S. , Montesinos, M. L. , Pernil, R. , Lichtlé, C. , Herrero, A. , and Flores, E. (2005) ABC-type neutral amino acid permease N-1 is required for optimal diazotrophic growth and is repressed in the heterocysts of *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 57: 1582–1592.
- Picossi, S. , Valladares, A. , Flores, E. , and Herrero, A. (2004) Nitrogen-regulated genes for the metabolism of cyanophycin, a bacterial nitrogen reserve polymer: Expression and mutational analysis of two cyanophycin synthetase and cyanophycinase gene clusters in heterocyst-forming cyanobacterium *Anabaena* sp. PCC 7120. *J Biol Chem* 279: 11582–11592.
- Pilak, O. , Mamat, B. , Vogt, S. , Hagemeyer, C. H. , Thauer, R. K. , Shima, S. , Vonnrhein, C. , Warkentin, E. , and Ermler, U. (2006). The crystal structure of the apoenzyme of the iron-sulfur cluster-free hydrogenase. *J Mol Biol* 358: 798–809.
- Pils D. , Wilken, C. , Valladares, A. , Flores, E. , and Schmetterer, G. (2004) Respiratory terminal oxidases in the facultative chemoheterotrophic and dinitrogen fixing cyanobacterium *Anabaena variabilis* strain ATCC 29413: Characterization of the cox2 locus. *Biochim Biophys Acta* 1659: 32–45.
- Popa, R. , Weber, P. K. , Pett-Ridge, J. , Finzi, J. A. , Fallon, S. J. , Hutcheon, I. D. , Nealson, K. H. , and Capone, D. G. (2007) Carbon and nitrogen fixation and metabolite exchange in and between individual cells of *Anabaena oscillarioides*. *Isme* 1–7. www.nature.com/ismej.

Porchia, A. C. , and Salerno, G. L. (1996) Sucrose biosynthesis in a prokaryotic organism: Presence of two sucrose-phosphate synthases in *Anabaena* with remarkable differences compared with the plant enzymes. *Proc Natl Acad Sci USA* 93: 13600–13604.

Porchia, A. C. , Curatti, L. , and Salerno, G. L. (1999) Sucrose metabolism in cyanobacteria: Sucrose synthase from *Anabaena* sp. strain PCC 7119 is remarkably different from the plant enzymes with respect to substrate affinity and amino-terminal sequence. *Planta* 210: 34–40.

Potts, M. , Angeloni, S. V. , Ebel, R. E. , and Bassam, D. (1992) Myoglobin in a cyanobacterium. *Science* 256: 1690–1692.

Pratte, B. S. , Eplin, K. , and Thiel, T. (2006) Cross-functionality of nitrogenase components NifH1 and VnfH in *Anabaena variabilis*. *J Bacteriol* 188: 5806–5811.

Privalle, L. S. , and Burris, R. H. (1984) D-erythrose supports nitrogenase activity in isolated *Anabaena* sp. strain 7120 heterocysts. *J Bacteriol* 157: 350–356.

Rai, A. K. , Pandey, K. D. , and Kashyap, A. K. (1978) Heterocyst differentiation and polarity in *Calothrix*. *New Phytol* 81: 647–651.

Rai, A. N. , Borthakur, M. , Singh, S. , and Bergman, B. (1989) Anthoceros-Nostoc symbiosis: Immunoelectronmicroscopic localization of nitrogenase, glutamine synthetase, phycoerythrin and ribulose-1,5-biphosphate carboxylase/oxygenase in the cyanobiont and the cultured (free-living) isolate *Nostoc* 7801. *J Gen Microbiol* 135: 385–395.

Rai, A. N. , Borthakur, M. , Söderbäck, E. , and Bergman, B. (1992) Immunogold localization of hydrogenase in the cyanobacterial- plant symbioses *Peltigera canina*, *Anthoceros punctatus* and *Gunnera magellanica*. *Symbiosis* 12: 131–144.

Rai, A. N. , Rowell, P. , and Stewart, W. D. P. (1982) Glutamate synthase activity of heterocysts and vegetative cells of the cyanobacterium *Anabaena variabilis* Kütz. *J Gen Microbiol* 128: 2203–2205.

Rajagopalan, R. , and Callahan, C. M. (2010) Temporal and spatial regulation of the four transcription start sites of *hetR* from *Anabaena* sp. strain PCC 7120. *J Bacteriol* 192: 1088–1096.

Ramasubramanian, T. S. , Pu, F. , and Golden, J. W. (1994a) Isolation of *Anabaena* sp. strain PCC 7120 *sigA* gene in a transcriptional interface selection. *J Bacteriol* 177: 6676–6678.

Ramasubramanian, T. S. , Wei, T.-F. , and Golden, J. W. (1994b) Two *Anabaena* sp. strain PCC 7120 DNA-binding factors interact with vegetative cell- and heterocyst specific genes. *J Bacteriol* 176: 1214–1223.

Ramasubramanian, T. S. , Wei, T.-F. , Oldham, A. K. , and Golden, J.W. (1996) Transcription of the *Anabaena* sp. strain PCC 7120 *ntcA* gene: Multiple transcripts and *NtcA* binding. *J Bacteriol* 178: 922–926.

Ramaswamy, K. S. , Carrasco, C. D. , Fatma, T. , and Golden, J. W. (1997) Cell-type specificity of the *Anabaena* *fdxN*-element rearrangement requires *xisH* and *xisl*. *Mol Microbiol* 23: 1241–1249.

Ramírez, M. E. , Hebbar, P. B. , Zhou, R. , Wolk, C. P. , and Curtis, S. E. (2005) *Anabaena* sp. strain PCC 7120 gene *devH* is required for synthesis of heterocyst glycolipid layer. *J Bacteriol* 187: 2326–2331.

Ran, L. , Larsson, J. , Vigil-Stenman, T. , Nylander, J. A. A. , Ininbergs, K. , Zheng, W.-W. , Lapidus, A. , Lowry, S. , Haselkorn, R. , and Berman, B. (2010) Genome erosion in a nitrogen-fixing vertically transmitted endosymbiotic multicellular cyanobacterium. *PLoS ONE* 5: e11486. doi:10.1371/journal.pone.0011486

Rawson, D. M. (1985) The effects of exogenous amino acids on growth and nitrogenase activity in the cyanobacterium *Anabaena cylindrica* PCC 7122. *J Gen Microbiol* 131: 2549–2554.

Ray, T. B. , Mayne, B. C. , Tola, Jr., R. E. , and Peters, G. A. (1979) *Azolla*-*Anabaena* relationship. VIII. Photosynthetic characterization of the association and individual partners. *Plant Physiol* 64: 791–795.

Razquin, P. , Fillat, M. F. , Schmitz, S. , Stricker, O. , Böhme, H. , Gómez-Moreno, C. , and Peleato, M. L. (1996) Expression of ferredoxin-NADP⁺ reductase in heterocysts of *Anabaena* sp. *Biochem J* 316: 157–160.

Razquin, P. , Schmitz, S. , Peleato, M. L. , Fillat, M. F. , Gómez-Moreno, C. , and Böhme, H. (1995) Differential activities of heterocyst ferredoxin, vegetative cell ferredoxin, and flavodoxin as electron carriers in nitrogen fixation and photosynthesis in *Anabaena* sp. *Photosynth Res* 43: 35–40.

Reddy, P. M. , and Talpasayi, E. R. S. (1974) Heterocyst formation in a blue-green alga, *Cylindrospermum*. *Nature (London)* 248: 493–494.

Reddy, P. M. , Conway, C. M. , and Fisher, R. W. (1989) Tunicamycin suppresses differentiation and stimulates dedifferentiation of heterocysts in the cyanobacterium *Anabaena azollae* Straus. *Curr Microbiol* 19: 109–114.

Reddy, P. M. , Spiller, H. , Albrecht, S. L. , and Shanmugam, K. T. (1996) Photodissimilation of fructose to H₂ and CO₂ by a dinitrogen fixing cyanobacterium *Anabaena variabilis*. *Appl Environ Microbiol* 62: 1220–1226.

Renström-Kellner, E. , Rai, A. N. , and Bergman, B. (1990) Correlation between nitrogenase and glutamine synthetase expression in the cyanobacterium *Anabaena cylindrica*. *Physiol Plant* 80: 12–19.

Reyes, J. C. , and Florencio, F. J. (1994) A new type of glutamine synthetase in cyanobacteria: The protein encoded by the *glnN* gene supports nitrogen assimilation in *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 176: 1260–1267.

Reyes, J. C. , Muro-Pastor, M. I. , and Florencio, F. J. (1997) Transcription of glutamine synthetase genes (*glnA* and *glnN*) from the cyanobacterium *Synechocystis* sp. strain PCC 6803 is differently regulated in response to nitrogen availability. *J Bacteriol* 179: 2678–2689.

Rice, D. , Mazur, B. J. , and Haselkorn, R. (1982) Isolation and physical mapping of nitrogen fixation genes from the cyanobacterium *Anabaena* 7120; *J. Biol. Chem.* 257: 13157–13163.

Rippka, R. , Deruelles, J. , Waterbury, J. B. , Herdman, M. , and Stanier, R. Y. (1979) Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *J Gen Microbiol* 111: 1-61.

Risser, D. D. , and Callahan, S. M. (2007) Mutagenesis of *hetR* reveals amino acids necessary for *HetR* function in the heterocystous cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 189: 2460–2467.

Risser, D. D. , and Callahan, S. M. (2008) *HetF* and *PatA* control levels of *HetR* in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 190: 7645–7654.

Risser, D. D. , and Callahan, S. M. (2009) Genetic and cytological evidence that heterocyst patterning is regulated by inhibitor gradients that promote activator decay. *Proc Natl Acad Sci USA* 106: 19884–19888.

Rodgers, G. A. , and Stewart, W. D. P. (1977) The cyanophyte-hepatic symbiosis. I. Morphology and physiology. *New Phytol* 78: 441–458.

Rodríguez, H. , Rivas, J. , Gurrero, M. G. , and Losada, M. (1990) Ca²⁺ requirement for aerobic nitrogen fixation by heterocystous blue-green algae. *Plant Physiol* 92: 886–890.

Rogerson, A. C. (1979) Modifiers of heterocyst repression and spacing and formation of heterocysts without nitrogenase in the cyanobacterium *Anabaena variabilis*. *J Bacteriol* 140: 213-219.

Rowell, P. , and Stewart, W. D. P. (1975) Alanine dehydrogenase of N₂ -fixing blue-green alga, *Anabaena cylindrica*. Arch Microbiol 107: 115–124.

Rowell, P. , Enticott, S. , Stewart, W. D. P. (1977) Glutamine synthetase and nitrogenase activity in the blue-green alga *Anabaena cylindrica*. New Phytol 79: 41–54.

Rowell, P. , Sampaio, M. J. A. M. , Ladha, J. K. , and Stewart, W. D. P. (1979) Alteration of cyanobacterial glutamine synthetase activity in vivo in response to light and NH₄⁺. Arch Microbiol 120: 195–200.

Ruppert, U. , Irmiler, A. , Kloft, N. , and Forchhammer, K. (2002) The novel protein phosphatase PphA from *Synechocystis* PCC 6803 controls dephosphorylation of the signaling protein PII. Mol Microbiol 44: 855–864.

Sakr, S. , Jeanjean, R. , Zhang, C.-C. , and Arcondeguy, T. (2006) Inhibition of cell division suppresses heterocyst development in *Anabaena* sp. strain PCC 7120. J Bacteriol 188: 1396–1404.

Sauer, J. , Dirmeier, U. , and Forchhammer, K. (2000) The *Synechococcus* strain PCC 7942 glnN product (glutamine synthetase III) helps in the recovery from prolonged nitrogen chlorosis. J Bacteriol 182: 5615–5619.

Sauer, J. , Gori, M. , and Forchhammer, K. (1999) Nitrogen starvation in *Synechococcus* PCC 7942: Involvement of glutamine synthetase and NtcA in phycobiliprotein degradation and survival. Arch Microbiol 172: 247–255.

Saville, B. , Straus, N. , and Coleman, J. R. (1987) Contiguous organization of nitrogenase genes in a heterocystous cyanobacterium. Plant Physiol 85: 26–29.

Sawa, Y. , Tani, M. , Murata, K. , Shibata, H. , and Ochiai, H. (1994) Purification and characterization of alanine dehydrogenase from a cyanobacterium, *Phormidium lapideum*. J Biol Chem 116: 995–1000.

Schiefer, W. , Schütz, K. , Hachtel, W. , and Happe, T. (2002) Molecular cloning and characterization of hetR genes from filamentous cyanobacteria. Biochim Biophys Acta 1577: 139–143.

Schilling, N. , and Ehrnsperger, K. (1985) Cellular differentiation of sucrose metabolism in *Anabaena variabilis*. Z Naturforsch 40: 776–779.

Schmetterer, G. , Valladares, A. , Pils, D. , Steinbach, S. , Pacher, M. , Muro-Pastor, A. M. , Flores, E. , and Herrero, A. (2001) The coxBAC operon encodes a cytochrome c oxidase required for heterotrophic growth in the cyanobacterium *Anabaena variabilis* strain ATCC 29413. J Bacteriol 183: 6429–6434.

Schmitz, O. , Boison, G. , Hilscher, R. , Hundeshagen, B. , Zimmer, W. , Lottspeich, F. , and Böthe, H. (1995) Molecular biological analysis of a bidirectional hydrogenase from cyanobacteria. Eur J Biochem 233: 266–276.

Schmitz, O. , Boison, G. , Salzmann, H. , Bothe, H. , Schütz, K. , Wang, S. , and Happe, T. (2002) HoxE-a subunit specific for the pentameric bidirectional hydrogenase complex (HoxEFUYH) of cyanobacteria. Biochim Biophys Acta 1554: 66–74.

Schmitz, O. , Kentenich, T. , Zimmer, W. , Hundeshagen, B. , and Böthe, H. (1993) Identification of the nifJ gene encoding for pyruvate: ferredoxin oxidoreductase in dinitrogen fixing cyanobacteria. Arch Microbiol 160: 62–67.

Schmitz, S. , Schrautemeier, B. , and Böhme, H. (1993) Evidence from directed mutagenesis that positively charged amino acids are necessary for interaction of nitrogenase with the [2Fe-2S] heterocyst ferredoxin (FdxH) from the cyanobacterium *Anabaena* sp. strain PCC 7120. Mol Gen Genet 240: 455–460.

Schrautemeier, B. , and Böhme, H. (1985) A distinct ferredoxin for nitrogen fixation isolated from heterocysts of the cyanobacterium *Anabaena variabilis*. FEBS Lett 184: 304–308.

Schrautemeier, B. , Böhme, H. , and Böger, P. (1984) In vitro studies on pathways and regulation of electron transport to nitrogenase with a cell-free extract from heterocysts of *Anabaena variabilis*. Arch Microbiol 137: 14–20.

Schrautemeier, B. , Cassing, A. , and Böhme, H. (1994) Characterization of the genome region encoding an fdxH-type ferredoxin and a new [2Fe-4S] ferredoxin from the non-heterocystous, nitrogen fixing cyanobacterium *Plectonema boryanum*. J Bacteriol 176: 1037–1046.

Schrautemeier, B. , Neveling, U. , and Schmitz, S. (1995) Distinct and differently regulated Mo-dependent nitrogen fixing systems evolved for heterocysts and vegetative cells of *Anabaena variabilis* ATCC 29413: Characterization of the fdxH1/2 gene regions as part of nif1/2 gene clusters. Mol Microbiol 18: 357–369.

Schriek, S. , Kahmann, V. , Staiger, D. , Pistorius, E. K. , and Michel, P. (2009) Detection of an L-amino acid dehydrogenase activity in *Synechocystis* sp. PCC 6803. J Exp Bot 60: 1035–1046. doi:10.1093/jxb/ern352

Seabra, R. , Santos, R. , Moradas-Ferreira, P. , and Tamagnini, P. (2009) Immunolocalization of the uptake hydrogenase in the marine cyanobacterium *Lyngbya majuscula* CCAP 1446/4 and two Nostoc strains. FEMS Microbiol Lett 292: 57–62.

Sedelnikova, S. , Rice, D. W. , Shibata, H. , Sawa, Y. , and Baker, P. J. (1998) Crystallization of alanine dehydrogenase from *Phormidium lapideum*. Acta Cryst 54: 407–408.

Sharma, P. (1984) Heterocyst and akinete induction with altered pattern in *Anabaena cylindrica*, caused by neopeptone. Arch Microbiol 139: 196–201.

Sharma, P. , and von Hofsten, A. (1987) Ultrastructural studies of heterocyst induction by neopeptone in *Anabaena cylindrica*. FEMS Microbiol Lett 48: 127–131.

Sherman, D. M. , Tucker, D. , and Sherman, L. A. (2000) Heterocyst development and localization of cyanophycin in N₂ -fixing cultures of *Anabaena* sp. PCC 7120 (Cyanobacteria). J Phycol 36: 932–941.

Shi, L. , Li, J.-H. , Cheng, Y. , Wang, L. , Chen, W.-L. , and Zhang, C.-C. (2007) Two genes encoding protein kinases of the HstK family are involved in the synthesis of the minor heterocyst-specific glycolipid in the cyanobacterium *Anabaena* sp. strain PCC 7120. J Bacteriol 189: 5075–5081. doi:10.1128/JB.00323-07

Shi, Y. , Zhao, W. , Zhang, W. , Ye, Z. , and Zhao, J. (2006) Regulation of intracellular free calcium concentration during heterocyst differentiation by HetR and NtcA in *Anabaena* sp. PCC 7120. Proc Natl Acad Sci USA 103: 11334–11339. doi:10.1073/pnas.0602839103

Shively, J. M. (1974) Inclusion bodies of prokaryotes. Annu Rev Microbiol 28: 167–187.

Silhavy, T. J. , and Beckwith, J. R. (1985) Use of lac fusions for the study of biological problems. Microbiol Rev 49: 398–418.

Silvester, W. B. (1976) Endophyte adaption in *Gunnera-Nostoc* symbiosis. In: Nutman, P. S. . (Ed.) Symbiotic Nitrogen Fixation in Plants, Vol 7. Cambridge University Press, Cambridge, UK. pp. 521–538.

Simon, R. D. (1971) Cyanophycin granules from the blue-green alga *Anabaena cylindrica*: A reserve material consisting of copolymers of aspartic acid and arginine. Proc Natl Acad Sci USA 68: 265–267.

Simon, R. D. (1973a) The effect of chloramphenicol on the production of cyanophycin granule polypeptide in the blue-green alga *Anabaena cylindrica*. Arch Microbiol 92: 115–122.

Simon, R. D. (1973b) Measurement of the cyanophycin granule peptide contained in the blue-green alga *Anabaena cylindrica*. J Bacteriol 114: 1213–1216.

Simon, R. D. (1976) The biosynthesis of multi-L-arginyl poly (L-aspartic acid) in the filamentous cyanobacterium *Anabaena cylindrica*. *Biochim Biophys Acta* 422: 407–418.

Simon, R. D. (1987) Inclusion bodies in the cyanobacteria: Cyanophycin, polyphosphate, polyhedral bodies. In: Fay, P. , and Van Baalen, C . (Eds.) *The Cyanobacteria*. Elsevier Publishers Amsterdam, The Netherlands. pp. 199–225.

Simon, R. D. , and Weathers, J. P. (1976) Determination of the structure of the novel polypeptide containing aspartic acid and arginine which is found in cyanobacteria. *Biochim Biophys Acta* 420: 166–176.

Simpson, F. B. , and Burris, R. H. (1984) A nitrogen pressure of 50 atmospheres does not prevent evolution of hydrogen by nitrogenase. *Science* 224: 1095–1097.

Singh, H. N. , Ladha, J. K. , and Kumar, H. D. (1977) Genetic control of heterocyst formation in the blue-green algae *Nostoc muscorum* and *Nostoc linckia*. *Arch Microbiol* 114: 155–159.

Singh, H. N. , and Srivastava, B. S. (1968) Studies on morphogenesis in a blue-green alga. I. Effect of inorganic nitrogen sources on developmental morphology of *Anabaena doliolum*. *Can J Microbiol* 14: 1341–1346.

Singh R. N. , and Tiwari, D. N. (1970) Frequent heterocyst germination in the blue-green alga *Gloeotrichia ghosei* Singh. *J Phycol* 6: 172–176.

Singh, R. N. , Tiwari, D. N. , and Singh, V. P. (1972) Genetic basis of cellular differentiation in blue-green algae. In: Desikachary, T. V. . (Ed.) *The Biology of Blue-green Algae*. University of Madras, Madras. pp. 27–37.

Sjoholm, J. , Oliveira, P. , and Lindblad, P. (2007) Transcriptional regulation of the bidirectional hydrogenase in the cyanobacterium *Nostoc* sp. strain PCC 7120. *Appl Environ Microbiol* 73: 5435–5446.

Smith, R. J. , and Wilkins, A. (1988) A correlation between intracellular calcium and incident irradiance in *Nostoc* 6720. *New Phytol* 109: 157–161.

Smith, R. J. , Hobson, S. , and Ellis, I. R. (1987) Evidence for calcium-mediated regulation of heterocyst frequency and nitrogenase activity in *Nostoc* 6720. *New Phytol* 105: 531–541.

Smith, R. L. , Kumar, D. , Xiankong, Z. , Tabita, F. R. , and Van Baalen, C. (1985) H₂, N₂ and O₂ metabolism by isolated heterocysts from *Anabaena* sp. strain CA. *J Bacteriol* 162: 565–570.

Smith, R. V. , and Evans, M. C. W. (1970) Soluble nitrogenase from vegetative cells of the blue-green alga *Anabaena cylindrica*. *Nature (London)* 225: 1253–1254.

Smith, R. V. , and Evans, M. C. W. (1971) Nitrogenase activity in cell-free extracts of the blue-green alga, *Anabaena cylindrica*. *J Bacteriol* 105: 913–917.

Smith, R. V. , Noy, R. J. , and Evans, M. C. W. (1971) Physiological electron donor to the nitrogenase of the blue-green alga *Anabaena cylindrica*. *Biochim Biophys Acta* 253: 104–109.

Spence, D. W. , and Stewart, W. D. P. (1986) Proline inhibits N₂ -fixation in *Anabaena* 7120. *Biochem Biophys Res Commun* 139: 940–946.

Soriente, A. , Gambacorta, A. , Trincone, A. , Sili, C. , Vincenzini, M. , and Sudano, G. (1993) Heterocyst glycolipids of the cyanobacterium *Cyanospira rippkae*. *Phytochemistry* 33: 393–396.

Soriente, A. , Sodano, G. , Gambacorta, A. , and Trincone, A. (1992) Structure of the heterocyst “glycolipids” of the marine cyanobacterium *Nodularia harveyana*. *Tetrahedron* 48: 5375–5384.

Spence, D. W. , and Stewart, W. D. P. (1986) Proline inhibits N₂ -fixation in *Anabaena* 7120. *Biochem Biophys Res Commun* 139: 940–946.

Spence, D. W. , and Stewart, W. D. P. (1987) Heterocystless mutants of *Anabaena* PCC 7120 with nitrogenase activity. *FEMS Microbiol Lett* 40: 119–122.

Spratt, E. R. (1911) Some observations of the life-history of *Anabaena cycadeae*. *Ann Bot* 25: 369–380.

Stacey, G. , Bottomley, P. J. , Van Baalen, C. , and Tabita, F. R. (1979) Control of heterocyst and nitrogenase synthesis in cyanobacteria. *J Bacteriol* 137: 321–326.

Stanier, R. Y. , and Cohen-Bazire, G. (1977) The photosynthetic prokaryotes: the cyanobacteria. *Annu Rev Microbiol* 31: 225–274.

Stanier, R. Y. , Kunisawa, R. , Mandel, M. , and Cohen-Bazire, G. (1971) Purification and properties of unicellular blue-green algae (order Chroococcales). *Bacteriol Rev* 35: 171–205.

Steincke, F. (1932) Das Auskeimen alter Heterocysten bei *Calothrix weberi*. (cited from Desikachary, 1959).

Stewart, W. D. P. (1964) The effect of available nitrate and ammonium nitrogen on the growth of two nitrogen-fixing blue-green algae. *J Exp Bot* 15: 138–145.

Stewart, W. D. P. (1980) Some aspects of structure and function in nitrogen fixing cyanobacteria. *Annu Rev Microbiol* 34: 497–536.

Stewart, W. D. P. , and Rowell, P. (1975) Effects of L-methionine-DL-sulphoximine on the assimilation of newly fixed ammonia, acetylene reduction and heterocyst formation in *Anabaena cylindrica*. *Biochem Biophys Res Commun* 65: 846–856.

Stewart, W. D. P. , and Singh, H. N. (1975). Transfer of nitrogen-fixing (nif) genes in the blue-green alga *Nostoc mucorum*. *Biochem Biophys Res Commun* 62: 62–69.

Stewart, W. D. P. , Fitzgerald, G. P. , and Burris, R. H. (1968) Acetylene reduction by nitrogen-fixing blue-green algae. *Arch Microbiol* 62: 336–348.

Stewart, W. D. P. , Haystead, A. , and Pearson, H. W. (1969) Nitrogenase activity in heterocysts of blue-green algae. *Nature (London)* 224: 226–228.

Stock, J. B. , Stock, A. M. , and Motten, J. M. (1990) Signal transduction in bacteria. *Nature (London)* 344: 395–400.

Strasser, P. , and Falkner, G. (1986) Characterization of the glutamate/aspartate transport system in a symbiotic *Nostoc* sp. *Planta* 168: 381–385.

Strauss, H. , Misselwitz, R. , Labudde, D. , Nicklisch, S. , and Baier, K. (2002) NblA from *Anabaena* sp. PCC 7120 is a mostly α -helical protein undergoing reversible trimerization in solution. *Eur J Biochem* 269: 4617–4624. doi:10.1046/j.1432-1033.2002.03161.x

Stucken, K. , John, U. , Cembella, A. , Murillo, A. A. , Soto-Liebe, K. , Fuentes-Valdés, J. J. , Friedel, M. , Plominsky, A. M. , Vásquez, M. , and Glöckner, G. (2010) The smallest known genomes of multicellular toxic cyanobacteria: Comparison of minimal gene sets for linked traits and the evolutionary implications. *PLoS ONE* 5: e9235. doi: 10.1371/journal.pone.0009235

Su, Z. , Oلمان, V. , Mao, F. , and Xu, Y. (2005) Comparative genomic analysis of NtcA regulons in cyanobacteria: regulation of nitrogen assimilation and its coupling to photosynthesis. *Nucleic Acids Res* 33: 5156–5171.

Summers, M. L. , Wallis, J. G. , Campbell, E. L. , and Meeks, J. C. (1995) Genetic evidence of a major role for glucose-6-phosphate dehydrogenase in nitrogen fixation and dark growth of the cyanobacterium *Nostoc* sp. strain ATCC 29133. *J Bacteriol* 177: 6184–6194.

Suzuki, A. , and Knaff, D. B. (2005) Glutamate synthase: Structural, mechanistic and regulatory properties and role in the amino acid metabolism. *Photosynth Res* 83: 193–217.

Talpasayi, E. R. S. and Bahal, M. (1967) Cellular differentiation in *Anabaena cylindrica*. *Zeitschrift Pflanzenphysiol* 56: 100–107

Talpasayi, E. R. S. , and Kale, K. S. (1967) Induction of heterocysts in the blue-green alga *Anabaena ambigua*. *Curr Sci* 36: 218–219

Tamagnini, P. , Axelsson, R. , Lindberg, P. , Oxelfelt, F. , Wüschiers, R. , and Lindblad, P. (2002) Hydrogenases and hydrogen metabolism of cyanobacteria. *Microbiol Mol Biol Rev* 66: 1–20.

Tamagnini, P. , Costa, J.-L. , Almeida, L. , Oliveira, M.-J. , Salema, R. , and Lindblad, P. (2000) Diversity of cyanobacterial hydrogenases, a molecular approach. *Curr Microbiol* 40: 356–361.

Tamagnini, P. , Leitão, E. , and Oxelfelt, F. (2005) Uptake hydrogenase in cyanobacteria: Novel input from non-heterocystous strains. *Biochem Soc Trans* 33: 67–69.

Tamagnini, P. , Leitão, E. , Oliveira, P. , Ferreira, D. , Pinto, F. , Harris, D. , Heidorn, T. , and Lindblad, P. (2007) Cyanobacterial hydrogenases: Diversity, regulation and applications. *FEMS Microbiol Rev* 31: 692–720.

Tamagnini, P. , Oxelfelt, F. , Salema, R. , and Lindblad, P. (1995) Immunological characterization of hydrogenases in the nitrogen-fixing cyanobacterium *Nostoc* sp. strain PCC 73102. *Curr Microbiol* 31: 102–107.

Tamagnini, P. , Troshina, O. , Oxelfelt, F. , Salema, R. , and Lindblad, P. (1997) Hydrogenases in *Nostoc* sp. strain PCC 73102, a strain lacking a bidirectional enzyme. *Appl Environ Microbiol* 63: 1801–1807.

Tanigawa, R. , Shirokane, M. , Maeda Si, S. , Omata, T. , Tanaka, K. , and Takahashi, H. (2002). Transcriptional activation of NtcA-dependent promoters of *Synechococcus* sp. PCC 7942 by 2-oxoglutarate in vitro. *Proc Natl Acad Sci USA* 99: 4251–4255.

Tano, H. , Ishizuka, M. , and Sone, N. (1991) The cytochrome c oxidase genes in blue-green algae and characteristics of the deduced protein sequence for subunit II of the thermophilic cyanobacterium *Synechococcus vulcanus*. *Biochem Biophys Res Commun* 181: 437–442.

Tel-Or, E. , and Stewart, W. D. P. (1976) Photosynthetic electron transport, ATP synthesis and nitrogenase activity in isolated heterocysts of *Anabaena cylindrica*. *Biochim Biophys Acta* 423: 189–195.

Tel-Or, E. , and Stewart, W. D. P. (1977) Photosynthetic components and activities of nitrogen-fixing isolated heterocysts of *Anabaena cylindrica*. *Proc R Soc B London* 198: 61–86.

Tel-Or, E. , Luijk, L. W. , and Packer, L. (1977) An inducible hydrogenase in cyanobacteria enhances N₂ fixation. *FEBS Lett* 78: 49–52.

Tel-Or, E. , Luijk, L. W. , and Packer, L. (1978) Hydrogenase in N₂ -fixing cyanobacteria. *Arch Biochem Biophys* 185:185–194.

Thiel, T. (1988) Transport of leucine in the cyanobacterium *Anabaena variabilis*. *Arch Microbiol* 149: 466–470.

Thiel, T. (1993) Characterization of genes for an alternative nitrogenase in the cyanobacterium *Anabaena variabilis*. *J Bacteriol* 175: 6276–6286.

Thiel, T. (1994) Genetic analysis of cyanobacteria. In: Bryant, D. A. . (Ed.) *The Molecular Biology of Cyanobacteria*. Kluwer Dordrecht, The Netherlands. pp. 581–611.

Thiel, T. (1996) Isolation and characterization of the nifEN genes of the cyanobacterium *Anabaena variabilis*. *J Bacteriol* 178: 4493–4499.

Thiel, T. , and Leone, M. (1986) Effect of glutamine on growth and heterocyst differentiation in the cyanobacterium *Anabaena variabilis*. *J Bacteriol* 168: 769–774.

Thiel, T. , and Pratte, B. (2001) Effect on heterocyst differentiation of nitrogen fixation in vegetative cells of the cyanobacterium *Anabaena variabilis* ATCC 29413. *J Bacteriol* 183: 280–286.

Thiel, T. , and Wolk, C. P. (1983) Metabolic activities of isolated akinetes of the cyanobacterium *Nostoc spongiaeforme*. *J Bacteriol* 156: 369–374.

Thiel, T. , Lyons, E. M. , and Erker, J. C. (1997) Characterization of genes for a second Mo-dependent nitrogenase in the cyanobacterium *Anabaena variabilis*. *J Bacteriol* 179: 5222–5225.

Thiel, T. , Lyons E. M. , Erker J. C. , and Ernst, A. (1995) A second nitrogenase in vegetative cells of a heterocyst-forming cyanobacterium. *Proc Natl Acad Sci USA* 92: 9358–9362.

Thiel, T. , Lyons, E. M. , and Thielemeier, J. (1999) Organization and regulation of two clusters of nif genes in the cyanobacterium *Anabaena variabilis*. In: Peschek, G.A. , Lossfeldhardt, W. , and Schmetterer, G. (Eds.) *The Phototrophic Prokaryotes*. Kluwer, Plenum. New York, USA. pp. 517–521.

Thomas, J. (1970) Absence of the pigments of photosystem II of photosynthesis in heterocysts of a blue-green alga. *Nature (London)* 228: 181–183.

Thomas, J. (1972) Relationship between age of culture and occurrence of the pigments of photosystem II of photosynthesis in heterocysts of a blue-green alga. *J Bacteriol* 110: 92–95.

Thomas, J. , and David, K. A. V. (1971) Studies on the physiology of heterocyst production in nitrogen-fixing blue-green alga *Anabaena* sp. L-31 in continuous culture. *J Gen Microbiol* 66: 127–131.

Thomas, J. , Meeks, J. C. , Wolk, C. P. , Shaffer, P. W. , Austin, S. M. , and Chien, W. S. (1977) Formation of glutamine from [13 N] ammonia, [13 N] dinitrogen and [14 C] glutamate by heterocysts isolated from *Anabaena cylindrica*. *J Bacteriol* 129: 1545–1555.

Tiwari, D. N. (1977) Pattern of heterocyst differentiation as a function of nitrogen fixing ability in blue-green alga *Nostoc linckia*. *Beitr Biol Pflanzen* 53: 177–186.

Tiwari, D. N. , Pandey, A. K. , and Mishra, A. K. (1981) Action of 2,4-dichlorophenoxyacetic acid and rifampicin on heterocyst differentiation in the blue-green alga, *Nostoc linckia*. *J Biosci* 3: 33–39.

Tiwari, D. N. , Yadava, P. K. , and Mishra, A. K. (1979) Developmental behaviour in mutants of *Gloeotrichia ghosei* defective in nitrogen fixation. *Microbios Lett* 12: 121–131.

Torrecilla, I. , Leganés, F. , Bonilla, I. , and Fernández-Piñas, F. (2000) Use of recombinant aequorin to study calcium homeostasis and monitor calcium transients in response to heat and cold shock in cyanobacteria. *Plant Physiol* 123: 161–175.

Torrecilla, I. , Leganés, F. , Bonilla, I. , and Fernández-Piñas, F. (2004) A calcium signal is involved in heterocyst differentiation in the cyanobacterium *Anabaena* sp. PCC 7120. *Microbiology* 150: 3731–3739. doi:10.1099/mic.0.27403-0

Toyoshima, M. , Sasaki, N. V. , Fujiwara, M. , Ehira, S. , Ohmori, M. , and Sato, N. (2010) Early candidacy for heterocyst differentiation into heterocysts in the filamentous cyanobacterium *Anabaena* sp. PCC 7120. *Arch Microbiol* 192: 23–31.

Tredici, M. R. , Margheri, M. C. , De Philippis, R. , and Materassi, R. (1990) The role of hydrogen metabolism in photoheterotrophic cultures of the cyanobacterium *Nostoc* sp. strain Cc isolated from *Cycas circinalis* L. *J Gen Microbiol* 136: 1009–1015.

Troshina, O. Y. , Serebrykova, L. T. , and Lindblad, P. (1996) Induction of H₂ -uptake and nitrogenase activities in the cyanobacterium *Anabaena variabilis* ATCC 29413: Effects of hydrogen and organic substrate. *Curr Microbiol* 33: 11–15.

Tumer, N. E. , Robinson, S. J. , and Haselkorn, R. (1983) Different promoters for the *Anabaena* glutamine synthetase gene during growth using molecular or fixed nitrogen. *Nature (London)* 306: 337–342.

Tyagi, V. V. S. (1973a) Effects of some metabolic inhibitors on heterocyst formation in the blue-green alga, *Anabaena doliolum*. *Ann Bot* 37: 361–368.

Tyagi, V. V. S. (1973b) Effects of actinomycin D on growth, heterocyst formation, and nucleic acid synthesis in the blue-green alga, *Anabaena doliolum*. *Curr Sci* 42: 343–346.

Tyagi, V. V. S. (1975) The heterocysts of blue-green algae (Myxophyceae). *Biol Rev* 50: 247–284.

Tyagi, V. V. S. , Ray, T. B. , Mayne, B. C. , and Peters, G. A. (1981) The *Azolla*- *Anabaena* relationship. XI. Phycobiliproteins in the action spectrum for nitrogenase-catalyzed acetylene reduction. *Plant Physiol* 68: 1479–1484.

Ulrich, L. E. , Koonin, E. V. , and Zhulin, I. B. (2005) One-component systems dominate signal transduction in prokaryotes. *Trends Microbiol* 13: 52–56.

Ungerer, J. L. , Pratte, B. S. , and Thiel, T. (2010) RNA processing of nitrogenase transcripts in the cyanobacterium *Anabaena variabilis*. *Arch Microbiol* 192: 3311–3320.

Vaishampayan, A. (1982) Amino acid nutrition in the blue-green alga *Nostoc muscorum*. *New Phytol* 90: 545–549.

Valladares, A. , Flores, E. , and Herrero, A. (2008) Transcription activation by NtcA and 2-oxoglutarate of three genes involved in heterocyst differentiation in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 190: 6126–6133.

Valladares, A. , Herrero, A. , Pils, D. , Schmetterer, G. , and Flores, E. (2003) Cytochrome c oxidase genes required for nitrogenase activity and diazotrophic growth in *Anabaena* sp. PCC 7120. *Mol Microbiol* 47: 1239–1249.

Valladares, A. , Maldener, I. , Muro-Pastor, A. M. , Flores, E. , and Herrero, A. (2007) Heterocyst development and diazotrophic metabolism in terminal respiratory oxidase mutants of the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* doi:10.1128/JB.00220-07

Valladares, A. , Muro-Pastor, A. M. , Herrero, A. , and Flores, E. (2004) The NtcA-dependent P1 promoter is utilized for *glnA* expression in N₂-fixing heterocysts of *Anabaena* sp. strain PCC 7120. *J Bacteriol* 186: 7337–7343.

Van De Water, S. D. , and Simon, R. D. (1982) Induction and differentiation of heterocysts in the filamentous cyanobacterium *Cylindrospermum licheniforme*. *J Gen Microbiol* 128: 917–925.

Van Gorkom, H. J. , and Donze, M. (1971) Localization of nitrogen fixation in *Anabaena*. *Nature (London)* 234: 231–232.

Vargas, W. , Cumino, A. , and Salerno, G. L. (2003) Cyanobacterial alkaline/neutral invertases. Origin of sucrose hydrolysis in the plant cytosol. *Planta* 216: 951–960.

Vazquez-Bermudez, M. F. , Herrero, A. , and Flores, E. (2002). 2- oxoglutarate increases the binding affinity of the ntcA (nitrogen control) transcription factor for the *Synechococcus* *glnA* promoter. *FEBS Lett* 512: 71–74.

Vega-Palas, M. A. , Flores, E. , and Herrero, A. (1992) NtcA, a global nitrogen regulator from the cyanobacterium *Synechococcus* that belongs to the Crp family of bacterial regulators. *Mol Microbiol* 6: 1853–1859.

Vega-Palas, M. A. , Madueno, F. , Herrero, A. , and Flores, E. (1990) Identification and cloning of a regulatory gene for nitrogen assimilation in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 172: 643–647.

Venkataraman, G. S. (1957) A note on the occurrence of three-pored heterocysts in *Mastigocladus laminosus* Cohn. *Curr Sci* 26: 254.

Vintila, S. , and El-Shehawy, R. (2007) Ammonium ions inhibit nitrogen fixation but does not affect heterocyst frequency in the bloom-forming *Nodularia spumigena* strain AV1. *Microbiology* 153: 3704–3712.

Voss, I. , Diniz, S. C. , Aboulmagd, E. , and Steinbuchel, A. (2004) Identification of the *Anabaena* sp. strain PCC 7120 cyanophycin synthetase as a suitable enzyme for production of cyanophycin in Gram-negative bacteria like *Pseudomonas putida* and *Ralstonia eutropha*. *Biomolecules* 5: 1588–1595.

Vyas, D. , and Kumar, H. D. (1995) Nitrogen fixation and hydrogen uptake in four cyanobacteria. *Int J Hydrogen Energy* 20: 163–168.

Walsby, A. E. (1985) The permeability of heterocysts to the gases nitrogen and oxygen. *Proc R Soc B London* 226: 345–366.

Walsby, A. E. (2007) Cyanobacterial heterocysts: Terminal pores proposed as sites of gas exchange. *Trends in Microbiol* 15: 340–349.

Walsby, A. E. , and Nichols, B. W. (1969) Lipid composition of heterocysts. *Nature (London)* 221: 673–674.

Wang, C. M. , Ekman, M. , and Bergman, B. (2004) Expression of cyanobacterial genes involved in heterocyst differentiation and dinitrogen fixation along a plant symbiosis development profile. *Mol Plant-Microbe Interactions* 17: 438–443.

Wang, Y. , and Xu, X. (2005) Regulation by hetC of genes required for heterocyst differentiation and cell division in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 187: 8489–8493.

Wang, Y. , Lechno-Yossef, S. , Gong, Y. , Fan, Q. , Wolk, C. P. , and Xu, X. (2007) Predicted glycosyl transferase genes located outside the HEP island are required for formation of heterocyst envelope polysaccharide in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 189: 5372–5378.

Watsyn, M. , Achatz, A. , Molitor, V. , and Peschek, G. A. (1988) Respiratory activities and aa3- type cytochrome oxidase in plasma and thylakoid membranes from vegetative cells and heterocysts of the cyanobacterium *Anabaena* ATCC 29413. *Biochim Biophys Acta* 935: 217–224.

Wealand, J. L. , Myers, J. A. , and Hirschberg, R. (1989) Changes in gene expression during nitrogen starvation in *Anabaena variabilis*. *J Bacteriol* 171: 1309–1313.

Weare, N. M. , and Benemann, J. R. (1973) Nitrogen fixation by *Anabaena cylindrica*. I. Localization of nitrogen fixation in the heterocysts. *Arch Microbiol* 90: 323–332.

Wei, T.-F. , Ramasubramanian, T. S. , and Golden, J. W. (1994) *Anabaena* sp. strain PCC 7120 ntcA gene required for growth on nitrate and heterocyst development. *J Bacteriol* 176: 4473–4482.

Wei, T.-F. , Ramasubramanian, T. S. , Pu, F. , and Golden, J. W. (1993) *Anabaena* sp. strain PCC 7120 bifA gene encoding a sequence-specific DNA-binding protein cloned by in vivo transcriptional interference selection. *J Bacteriol* 175: 4025–4035.

Weyman, P. D. , Pratte, B. , and Thiel, T. (2008) Transcription of hupSL in *Anabaena variabilis* ATCC 29413 is regulated by NtcA and not by hydrogen. *Appl Environ Microbiol* 74: 2103–2110.

Whitton, B. A. , and Peat, A. (1967) Heterocyst structure in *Chlorogloea fritschii*. *Arch Microbiol* 58: 324–338.

Wilcox, M. , Mitchison, G. J. , and Smith, R. J. (1973a) Pattern formation in the blue-green alga, *Anabaena*. I. Basic mechanisms. *J Cell Sci* 13: 707–723.

Wilcox, M. , Mitchison, G. J. , and Smith, R. J. (1973b) Pattern formation in the blue-green alga, *Anabaena*. II. Controlled proheterocyst regression. *J Cell Sci* 13: 637–649.

- Wildon, D. C. , and Mercer, F. V. (1963a) The ultrastructure of the heterocyst and akinete of the blue-green algae. *Arch Microbiol* 47: 19–31.
- Wildon, D. C. , and Mercer, F. V. (1963b) The ultrastructure of the vegetative cell of the blue-green algae. *Aus J Biol Sci* 16: 585–596.
- Wilson, G. A. , Bertrand, N. , Patel, Y. , Hughes, J. B. , Feil, E. J. , and Field, D. (2005) Orphans as taxonomically restricted and ecologically important genes. *Microbiology* 151: 2499–2501.
- Winkenbach, F. , and Wolk, C. P. (1973) Activities of enzymes of oxidative and reductive pentose phosphate pathways in heterocysts of a blue-green alga. *Plant Physiol* 52: 480–483.
- Winkenbach, F. , Wolk, C. P. and Jost, M. (1972) Lipids of membranes and the cell envelope in heterocysts of a blue-green alga. *Planta* 107: 69–80.
- Wolk, C. P. (1965) Control of sporulation in a blue-green alga. *Develop Biol* 12: 15–35.
- Wolk, C. P. (1967) Physiological basis of the pattern of vegetative growth of a blue-green alga. *Proc Natl Acad Sci USA* 57: 1246–1251.
- Wolk, C. P. (1968) Movement of carbon from vegetative cells to heterocysts in *Anabaena cylindrica*. *J Bacteriol* 96: 2138–2143.
- Wolk, C. P. (1975) Differentiation and pattern formation in filamentous blue-green algae. In: Gerhardt, P. , Costilow, R. N. , and Sadoff, H. L. (Eds.) *Spores IV*. American Society for Microbiology, Washington, DC., USA. pp. 85–96.
- Wolk, C. P. (1979) Intercellular interactions and pattern formation in filamentous cyanobacteria. In: S. Subtelny , and Konigsberg, I. R. (Eds.) *Determinants of Spatial Organization*. Academic Press, Inc., New York, N.Y., USA. pp. 247–266.
- Wolk, C. P. (1982) Heterocysts. In: Carr, N. G. , and Whitton, B. A. (Eds.) *The Biology of the Cyanobacteria*. Blackwell Scientific Publications, Ltd., Oxford, UK. pp. 359–386.
- Wolk, C. P. (1989) Alternative models for the development of the pattern of spaced heterocysts in *Anabaena* (Cyanophyta). *Plant Syst Evol* 164: 27–31.
- Wolk, C. P. (1996) Heterocyst formation. *Annu Rev Genet* 30: 59–78.
- Wolk, C.P. (2000) Heterocyst formation in *Anabaena*. In: Brun, Y.V. , and Shimkets, L.J. (Eds) *Prokaryotic Development*. American Society for Microbiology, Washington, DC., USA. pp. 83–104.
- Wolk, C. P. , and Schaffer, P. W. (1976) Heterotrophic micro- and macro-cultures of a nitrogen-fixing cyanobacterium. *Arch Microbiol* 110: 145–147.
- Wolk, C. P. , and Simon, R. D. (1969) Pigments and lipids of heterocysts. *Planta* 86: 92–97.
- Wolk, C. P. , and Quine, M. P. (1975) Formation of one dimensional patterns by stochastic processes and by filamentous blue-green algae. *Dev Biol* 46: 370–382.
- Wolk, C. P. , and Wojciuch, E. (1971a) Photoreduction of acetylene by heterocysts. *Planta* 97: 126–134.
- Wolk, C. P. , and Wojciuch, E. (1971b) Biphasic time course of solubilization of nitrogenase during cavitation of aerobically grown *Anabaena cylindrica*. *J Phycol* 7: 339–344.
- Wolk, C. P. , Austin, S. M. , Bortins, J. , and Galonsky, A. (1974) Autoradiographic localization of ¹³N after fixation of ¹³N-labelled nitrogen gas by a heterocyst forming blue-green alga. *J Cell Biol* 61: 440–453.
- Wolk, C. P. , Cai, Y. , and Panoff, J.-M. (1991) Use of transposon with luciferase as a reporter to identify environmentally responsive genes in a cyanobacterium. *Proc Natl Acad Sci USA* 88: 5355–5359.
- Wolk, C. P. , Cai, Y. , Cardemil, L. , Flores, E. , Hohn, B. , Murry, M. , Schmetterer, G. , Schrautemeier, B. , and Wilson, R. C. (1988) Isolation and complementation of mutants of *Anabaena* sp. strain PCC 7120 unable to grow aerobically on dinitrogen. *J Bacteriol* 170: 1239–1244.
- Wolk, C. P. , Elhai, J. , Kuritz, T. , and Holland, D. (1993) Amplified expression of a transcriptional pattern formed during development of *Anabaena*. *Mol Microbiol* 7: 441–445.
- Wolk, C. P. , Ernst, A. , and Elhai, J. (1994) Heterocyst metabolism and development. In: *The Molecular Biology of Cyanobacteria*, 2nd edn. Bryant, D. A. (Ed.) Kluwer, Dordrecht, The Netherlands. pp. 769–823.
- Wolk, C. P. , Fan, Q. , Zhou, R. , Huang, G. , Lechno-Yossef, S. , Kuritz, T. , and Wojciuch, E. (2007) Paired cloning vectors for complementation of mutations in the cyanobacterium *Anabaena* sp. strain PCC 7120. *Arch Microbiol* 188: 551–563.
- Wolk, C. P. , Thomas, J. , Shaffer, P. W. , Austin, S. M. , and Galonsky, A. (1976) Pathway of nitrogen metabolism after fixation of ¹³N-labeled nitrogen gas by the cyanobacterium *Anabaena cylindrica*. *J Biol Chem* 251: 5027–5034.
- Wolk, C. P. , Vonshak, A. , Kehoe, P. , and Elhai, J. (1984) Construction of shuttle vectors capable to conjugative transfer from *Escherichia coli* to nitrogen-fixing filamentous cyanobacteria. *Proc Natl Acad Sci USA* 81: 1561–1565.
- Wong, F. C. , and Meeks, J. C. (2001) The *hetF* gene product is essential to heterocyst differentiation and affects *HetR* function in the cyanobacterium *Nostoc punctiforme*. *J Bacteriol* 183: 2654–2661.
- Wu, X. , Lee, D. W. , Mella, R. A. , and Golden, J. W. (2007) The *Anabaena* sp. strain PCC 7120 *asr1734* gene encodes a negative regulator of heterocyst development. *Mol Microbiol* 64: 782–794. doi: 10.1111/j.1365-2958.2007.05698.x
- Wu, X. , Liu, D. , Lee, M. H. , and Golden, J. W. (2004) *patS* minigenes inhibit heterocyst development of *Anabaena* sp. strain PCC 7120. *J Bacteriol* 186: 6422–6429.
- Wünschiers, R. , Batur, M. , and Lindblad, P. (2003) Presence and expression of hydrogenase specific C-terminal endopeptidases in cyanobacteria. *BMC Microbiol* 3: 8.
- Xiankong, Z. , Tabita, F. R. , and Van Baalen, C. (1984) Nickel control of hydrogen production and uptake in *Anabaena* spp. strains CA and 1F. *J Gen Microbiol* 130: 1815–1818.
- Xu, W. L. , Jeanjean, R. , Liu, Y. D. , and Zhang, C. C. (2003) Pkn22 (*alr2502*) encoding a putative Ser/Thr kinase in the cyanobacterium *Anabaena* sp. PCC 7120 is induced by both iron starvation and oxidative stress and regulates the expression of *isiA*. *FEBS Lett* 553: 179–182.
- Xu, X. , and Wolk, C. P. (2001) Role for *hetC* in the transition to a non-dividing state during heterocyst differentiation in *Anabaena* sp. *J Bacteriol* 183: 393–396.
- Yamanaka, G. , and Glazer, A. N. (1983) Phycobiliproteins in *Anabaena* 7119 heterocysts. In: Papageorgiou, G. C. , and Packer, L. (Eds.) *Photosynthetic Prokaryotes: Cell Differentiation and Function*. Elsevier, New York, N.Y., USA. pp. 69–90.
- Ying, L. , Huang, X. , Huang, B. , Xie, J. , Zhao, J. , and Zhao, X. S. (2002) Fluorescence emission and absorption spectra of single *Anabaena* sp. strain PCC 7120 cells. *Photochem Photobiol* 76: 310–313.
- Yoon, H.-S. , and Golden, J. W. (1998). Heterocyst pattern formation controlled by a diffusible peptide. *Science* 282: 935–938.
- Yoon, H.-S. , and Golden, J. W. (2001) *PatS* and products of nitrogen fixation control heterocyst pattern. *J Bacteriol* 183: 2605–2613.

Yoon, H.-S. , Lee, M. H. , and Golden, J. W. (2003) *Anabaena* sp. strain PCC 7120 *hetY* gene influences heterocyst development. *J Bacteriol* 185: 6995–7000.

Yoshimura, H. , Okamoto, S. , Tsumuraya, Y. , and Ohmori, M. (2007) Group 3 sigma factor gene, *sigJ*, a key regulator of desiccation tolerance, regulates the synthesis of extracellular polysaccharide in cyanobacterium *Anabaena* sp. strain PCC 7120. *DNA Res* 14: 13–24.

Yoshino, F. , Ikeda, H. , Masukawa, H. , and Sakurai, H. (2007) High photobiological hydrogen production activity of a *Nostoc* sp. PCC 7422 uptake hydrogenase-deficient mutant with high nitrogenase activity. *Marine Biotechnol* 9: 101–112.

Young-Robbins, S. S. , Risser, D. D. , Moran J. R. , Haselkorn, R. , and Callahan, S. M. (2010) Transcriptional regulation of the heterocyst patterning gene *patA* from *Anabaena* sp. strain PCC 7120. *J Bacteriol* 192: 4732–4740. doi:10.1128/JB.00577-10

Zhang, C.-C. (1993) A gene encoding a protein related to eukaryotic protein kinases from the filamentous heterocystous cyanobacterium *Anabaena* PCC 7120. *Proc Natl Acad Sci USA* 90: 11840–11844.

Zhang, C.-C. , and Libs, L. (1998) Cloning and characterisation of the *pknD* gene encoding a eukaryotic-type protein kinase in the cyanobacterium *Anabaena* sp. PCC7120. *Mol Gen Genet* 258: 26–33.

Zhang, C.-C. , Friry, A. , and Peng, L. (1998) Molecular and genetic analysis of two closely linked genes that encode, respectively, a protein phosphatase 1/2A/2B homolog and a protein kinase homolog in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 180: 2616–2622.

Zhang, C.-C. , Huguenin, S. , and Friry, A. (1995) Analysis of genes encoding the cell division protein *FtsZ* and a glutathione synthetase homologue in the cyanobacterium *Anabaena* sp. PCC 7120. *Res Microbiol* 146: 445–455.

Zhang, C.-C. , Jang, J. , Sakr, S. and Wang, L. (2005) Protein phosphorylation on Ser, Thr and Tyr residues in cyanobacteria. *J Mol Biol Biotechnol* 9: 154–166. doi:10.1159/000089644

Zhang, C.-C. , Laurent, S. , Sakr, S. , Peng, L. , and Bédou, S. (2006) Heterocyst differentiation and pattern formation in cyanobacteria: A chorus of signals. *Mol Microbiol* 59: 367–375. doi:10.1111/j.1365-2958.2005.04979.x

Zhang, J. Y. , Chen, W. L. , and Zhang, C.-C. (2009) *hetR* and *patS*, two genes necessary for heterocyst pattern formation are wide spread in filamentous non-heterocyst-forming cyanobacteria. *Microbiology* 155: 1418–1426. doi:10.1099/mic.0.027540-0

Zhang, L.-C. , Chen, Y.-F. , Chen, W.-L. , and Zhang, C.-C. (2008) Existence of periplasmic barriers preventing green fluorescent protein diffusion from cell to cell in the cyanobacterium *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 70: 814–823.

Zhang, W. , Du, Y. , Khudyakov, I. , Fan, Q. , Gao, H. , Ning, D. , Wolk, C. P. , and Xu, X. (2007) A gene cluster that regulates both heterocyst differentiation and pattern formation in *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 66: 1429–1443. doi: 10.1111/j.1365-2598.2007.05997.x

Zhang, X. , Tabita, F. R. , and Van Baalen, C. (1984) Nickel control of hydrogen production and uptake in *Anabaena* spp. strains CA and IF. *J Gen Microbiol* 130: 1815–1818.

Zhang, X. , Zhao, F. , Guan, X. , Yang, Y. , Liang, C. , and Qin, S. (2007) Genome-wide survey of putative serine/threonine protein kinases in cyanobacteria. *BMC Genomics* 8: 395. doi: 10.1186/1471-2164-8-395

Zhang, Y. , Pu, H. , Wang, Q. , Cheng, S. , Zhao, W. , Zhang, Y. , and Zhao, J. (2007) *Pil* is important in regulation of nitrogen metabolism but not required for heterocyst formation in the cyanobacterium *Anabaena* sp. PCC 7120. *J Biol Chem* 282: 33641–33648.

Zhao, M.-X. , Jiang, Y. L. , He, Y.-X. , Chen, Y.-F. , Teng, Y.-B. , Chen, Y. , Zhang, C.-C. , and Zhou, C.-Z. (2010) Structural basis for the allosteric control of the global transcription factor *NtcA* by the nitrogen starvation signal 2-oxoglutarate. *Proc Natl Acad Sci USA* 107: 12487–12492. doi: 10.1073/pnas.1001556107

Zhao, W. , Ye, Z. , and Zhao, J. (2007) *RbrA*, a cyanobacterial rubrerythrin, functions as a FNR-dependent peroxidase in heterocysts in protection of nitrogenase from damage by hydrogen peroxide in *Anabaena* sp. PCC 7120. *Mol Microbiol* 66: 1219–1230. doi:10.1111/j.1365.2958.2007.05994.x

Zhao, Y. , Shi, Y. , Zhao, W. , Huang, X. , Wang, D. , Brown, N. , and Brand, J. (2005) *CcbP*, a calcium-binding protein from *Anabaena* sp. PCC 7120, provides evidence that calcium ions regulate heterocyst differentiation. *Proc Natl Acad Sci USA* 102: 5744–5748. doi:10.1073/pnas.051782102

Zhou, R. , and Wolk, C. P. (2003) A two-component system mediates developmental regulation of biosynthesis of a heterocyst polysaccharide. *J Biol Chem* 278: 19939–19946.

Zhou, R. , Wei, X. , Jiang, N. , Li, H. , Dong, Y. , His, K.-L. , and Zhao, J. (1998) Evidence that *HetR* protein is an unusual serine- type protease. *Proc Natl Acad Sci USA* 95: 4959–4963.

Zhu, J. , Kong, R. , and Wolk, C. P. (1998) Regulation of *hepA* of *Anabaena* sp. strain PCC 7120 by elements 5' from the gene and by *hepK*. *J Bacteriol* 180: 4233–4242.

Zhu, J. , Jäger, K. , Black, T. , Zarka, K. , Koksharova, O. , and Wolk, C. P. (2001) *HcwA*, an autolysin, is required for heterocyst maturation in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 183: 6841–6851.

Zhu, M. , Callahan, S. M. , and Allen, J. S. (2010) Maintenance of heterocyst patterning in a filamentous cyanobacterium. *J Biol Dyn* 4: 621–633.

Ziegler, K. , Diener, A. , Herpin, C. , Richter, R. , Deutzmann, R. , and Lockau, W. (1998) Molecular characterization of cyanophycin synthetase, the enzyme catalyzing the biosynthesis of the cyanobacterial reserve material multi-L-arginyl-poly-L-aspartate (cyanophycin). *Eur J Biochem* 254: 154–159.

Ziegler, K. , Stephan, D. P. , Pistorius, E. K. , Ruppel, H. G. , and Lockau, W. (2001) A mutant of the cyanobacterium *Anabaena variabilis* ATCC 29413 lacking cyanophycin synthetase. *FEMS Microbiol Lett* 196: 13–18.

Movements

Adams, D. G. (2001) How do cyanobacteria glide? *Microbiology Today* 28: 28-131.

Adams, D. G. , Ashworth, D. , and Nelmes, B. (1999) Fibrillar array in the cell wall of a gliding filamentous cyanobacterium. *J Bacteriol* 181: 181-884.

Alexandre, G. , and Zhulin, I. B. (2001) More than one way to sense chemicals. *J Bacteriol* 18: 18-4681.

Armitage, J. P. , and Hellingwerf, K. J. (2003) Light-induced behavioral responses ('phototaxis') in prokaryotes. *Photosynth Res* 76: 76-145.

Bardy, S. L. , Ng, Y. M. S. , and Jarrell, K. F. (2003) Prokaryotic motility structures. *Microbiology* 149: 149-295.

Bhaya, D. (2004) Light matters: phototaxis and signal transduction in unicellular cyanobacteria. *Mol Microbiol* 53: 745-754. doi:10.1111/j.1365-2598.2004.04160.x

Bhaya, D. , Bianco, N.R. , Bryant, D. , and Grossman, A. (2000) Type IV pilus biogenesis and motility in the cyanobacterium *Synechocystis* sp. PCC 6803. *Mol Microbiol* 37: 37-941.

Bhaya, D. , Nakasugi, K. , Fazeli, F. , and Burriesci, M. S. (2006) Phototaxis and impaired motility of *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 188: 7306-7310. doi:10.1128/JB.00573-06.

Bhaya, D. , Takahashi, A. , Shahi, P. , and Grossman, A. R. (2001a) Novel motility mutants of *Synechocystis* strain PCC 6803 generated by in vitro transposon mutagenesis. *J Bacteriol* 183: 183-6140.

Bhaya, D. , Takahashi, A. , and Grossman, A. R. (2001b) Light regulation of type IV pilus-dependent motility by chemosensorlike elements in *Synechocystis* PCC 6803. *Proc Natl Acad Sci USA* 98: 98-7540.

Bhaya, D. , Watanabe, N. , Ogawa, T. , and Grossman, A. R. (1999) The role of an alternative sigma factor in motility and pilus formation in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *Proc Natl Acad Sci USA* 96: 96-3188.

Biemann, H. P. , and Koshland, D. E. Jr . (1994) Aspartate receptors of *Escherichia coli* and *Salmonella typhimurium* bind ligand with negative and half-of-the-sites cooperativity. *Biochemistry* 33: 33-629.

Brahamsha, B. (1996) An abundant cell-surface polypeptide is required for swimming by the non-flagellated marine cyanobacterium *Synechococcus*. *Proc Natl Acad Sci USA* 93: 93-6504.

Brahamsha, B. (1999) Non-flagellar swimming in marine *Synechococcus*. *J Mol Microbiol Biotechnol* 1: 1-59.

Brock, T. D. (1978) *Thermophilic Microorganisms and Life at High Temperature*. Springer-Verlag, New York, N.Y, USA.

Castenholz, R. W. (1973) Movements. In: Carr, N.G. and Whitton, B.A. (Eds.) *The Biology of Blue-green Algae*. Blackwell Scientific Publications, Oxford, U.K. pp. 320-339.

Castenholz, R. W. (1982) Motility and taxes. In: Carr, N. G. and Whitton, B.A. (Eds.) *The Biology of Cyanobacteria*. Blackwell Scientific Publications, Oxford, U.K. pp. 413-439.

Castes, A.-M. , Houmard, J. , and Tandeau de Marsac, N. (1986) Is cell motility a plasmid-encoded function in the cyanobacterium *Synechocystis* 6803? *FEMS Microbiol Lett* 37: 37-277.

Choi, J. S. , Chung, Y. H. , Moon, Y. J. , Kim, C. , Watanabe, M. , Song, P. S. , Joe, C. O. , Bogorad, L. , and Park, Y. M. (1999) Photomovement of the gliding cyanobacterium *Synechocystis* PCC 6803. *Photochem Photobiol* 70: 70-95.

Clarke, S. , and Koshland D. E. Jr . (1979) Membrane receptors for aspartate and serine in bacterial chemotaxis. *J Biol Chem* 254: 254-9695.

Damerval, T. , Guglielmi, G. , Houmard, J. , and Tandeau de Marsac, N. (1991) *Harmogonium* differentiation in the cyanobacterium *Calothrix* : a photoregulated developmental process. *Plant Cell* 3: 3-191.

Dick, H. , and Stewart, W. D. P. (1980) The occurrence of fimbriae on a N₂-fixing cyanobacterium which occurs in lichen symbiosis. *Arch Microbiol* 109: 109-207.

Diehn, B. , Feinleib, M. , Haupt, W. , Hildebrand, E. , Lenci, F. , and Nultsch, W. (1979) Terminology of behavioral responses of motile microorganisms. *Photochem Photobiol* 26: 26-559.

Dienst, D. , Dühring, U. , Mollenkopt, H.-J. , Vogel, J. , Golecki, J. , Hess, W. R. , and Wilde, A. (2008) The cyanobacterial homologue of the RNA chaperone Hfq is essential for motility of *Synechocystis* sp. PCC 6803. *Microbiology* 154: 154-3134.

Guglielmi, G. , and Cohen-Bazire, G. (1982) Structure et distribution des pores et des perforations de l'enveloppe de peptidoglycane chez quelques cyanobacteries. *Protistologica* 18: 18-3923.

Ehlers, K. M. , Samuel, A. D. T. , Berg, H. C. , and Montgomery, R. (1996) Do cyanobacteria swim using traveling surface waves? *Proc Natl Acad Sci USA* 93: 93-6340.

Fiedler, B. , Borner, T. , and Wilde, A. (2005) Phototaxis in the cyanobacterium *Synechocystis* sp. PCC 6803: role of different photoreceptors. *Photochem Photobiol* 81: 81-1481.

Fiedler, B. , Broc, D. , Schubert, H. , Rediger, A. , Börner, T. , and Wilde, A. (2004) Involvement of cyanobacterial phytochromes in growth under different light qualities and quantities. *Photochem Photobiol* 79: 79-551.

Fukushima, Y. , Murai, Y. , Okajima, K. , Ikeuchi, M. , and Itoh, S. (2008) Photoreactions of Tyr8-and Gln50-mutated BLUF domains of the PixD protein of *Thermosynechococcus elongatus* BP-1. Photoconversion at low temperature without Tyr8. *Biochemistry* 47: 47-660.

Häder, D. P. (1987a) Photosensory behavior in prokaryotes. *Microbiol Rev* 51: 51-61.

Häder, D. P. (1987b) Photomovement In: Fay, P. , and van Baalen, C. (Eds.) *The Cyanobacteria*. Elsevier, New York, pp. 325-346.

Halfen, L. N. (1973) Gliding motility in *Oscillatoria*: ultrastructure and chemical characterization of the fibrillar layer. *J Phycol* 9: 9-248.

Halfen, L. N. (1979) Gliding movements. In: Haupt, W. , and Feinleib, M.E. (Eds.) *Encyclopedia of Plant Physiology*. Vol 7. Physiology of movements. Springer, Berlin Heidelberg, New York, pp. 250-267.

Halfen, L. N. , and Castenholz, R. W. (1970) Gliding in a blue-green alga: a possible mechanism. *Nature (London)* 225: 225-1163.

Halfen, L.N. , and Castenholz, R. W. (1971) Gliding in a blue-green alga, *Oscillatoria princeps*. *J Phycol* 7: 7-133.

Hayes, W. (1968) *The Genetics of Bacteria and their Viruses*. Blackwell Scientific Publications, Oxford, Edinburgh, UK. 2nd edn. 925 pp.

Hedger, J. , Holmquist, P. C. , Leigh, K. A. , Saraff, K. , Pomykal, C. , and Summers, M. L. (2009) Illumination stimulates cAMPReceptor protein dependent transcriptional activation from regulatory regions containing class I and class II promoter elements in *Synechocystis* sp. PCC 6803. *Microbiology* 155: 2994-3004. doi: 10.1099/mic0.028035-0.

Hoiczky, E. (2000) Gliding motility in cyanobacteria: observations and possible explanations. *Arch Microbiol* 174: 174-211.

Hoiczky, E. , and Baumeister, W. (1995) Envelope structure of four gilding filamentous cyanobacteria. *J Bacteriol* 177: 177-2387.

Hoiczky, E. , and Baumeister, W. (1997) Oscillin, an extracellular, Ca²⁺-binding glycoprotein essential for gliding motility of cyanobacteria. *Mol Microbiol* 26: 26-699.

Hoiczky, E. , and Baumeister, W. (1998) The junctional pore complex, a prokaryotic secretion organelle, is the molecular motor underlying gliding motility in cyanobacteria. *Curr Biol* 8: 8-1161.

Hoiczky, E. , and Hansel, A. (2000) Cyanobacterial cell walls: News from an unusual prokaryotic envelope. *J Bacteriol* 182: 182-1191.

Hazelbauer, G. L. , and Harayama, S. (1983) Sensory transduction in bacterial chemotaxis. *Int Rev Cytol* 81: 81-133.

Hood, E. E. , Armour, S. , Ownby, J. D. , Handa, A. K. , and Bressan, R. A. (1979) Effect of nitrogen starvation on the level of adenosine 3',5'-monophosphate in *Anabaena variabilis*. *Biochim Biophys Acta* 588: 588-593.

Huang, F. , Hedman, E. , Funk, C. , Kieselbach, T. , Schroder, W. P. , and Norling, B. (2004) Isolation of outer membrane of *Synechocystis* sp. PCC 6803 and its proteomic characterization. *Mol Cell Proteomics* 3: 3-586.

Huang, F. , Parmryd, I. , Nilsson, F. , Persson, A. L. , Pakrasi, H. B. , Andersson, B. , and Norling, B. (2002) Proteomics of *Synechocystis* sp. strain PCC 6803: Identification of plasma membrane proteins. *Mol Cell Proteomics* 1: 1-956.

Hughes, J. , Lamparter, T. , Mittmann, F. , Hartmann, E. , Gartner, W. , Wilde, A. , and Borner, T. (1997) A prokaryotic phytochrome. *Nature (London)* 386: 663.

Ishizuka, T. , Shimada, T. , Okajima, K. , Yoshihara, S. , Ochiai, Y. , Katayama, M. , and Ikeuchi, M. (2006) Characterization of cyanobacteriochrome TePixJ from a thermophilic cyanobacterium *Thermosynechococcus elongatus* strain BP-1. *Plant Cell Physiol* 47: 47-1251.

Jeon, J. , and Dobryin, A.V. (2005) Polymer containment and bacterial gliding motility. *Eur Phy J (E)* 17: 17-361.

Kamei, A. , Ogawa, T. , and Ikeuchi, M. (1998) Identification of a novel gene (slr2301) involved in high-light resistance in the cyanobacterium *Synechocystis* sp. PCC 6803. In: Garab, G. (Ed.) *Photosynthesis : Mechanisms and Effects*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 2901-2905.

Kamei, A. , Yuasa, T. , Orikawa, K. , Geng, X. X. , and Ikeuchi, M. (2001) A eukaryote type protein kinase, SpkA, is required for normal motility of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 183: 183-1505.

Kaneko, T. , Nakamura, Y. , Wolk, C. P. , Kuritz, T. , Sasamoto, S. , Watanabe, A. , Iriguchi, M. , Ishikawa, A. , Kawashima, K. , Kimura, T. , Kishida, Y. , Kohara, M. , Matsunoto, M. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Shimpo, S. , Sugimoto, M. , Takazawa, M. , Yamada, M. , Yasuda, M. , and Tabata, S. (2001) Complete genome sequence of the filamentous nitrogenfixing cyanobacterium *Anabaena* sp. strain PCC 7120. *DNA Res* 8: 205-213; 227-253.

Kaneko, T. , Sato, S. , Kotani, H. , Tanaka, A. , Asamizu, E. , Nakamura, Y. , Miyajima, N. , Hirose, M. , Sugira, M. , Sasamoto, S. , Kimura, T. , Hosouchi, T. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Naruo, K. , Okumura, S. , Shimpo, S. , Takeuchi, C. , Wada, T. , Watanabe, A. , Yamada, M. , Yasuda, M. , and Tabata, S. (1996) Sequence analysis of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. II. Sequence determination of the entire genome and assignment of potential proteincoding regions. *DNA Res* 3: 3-109.

Kasahara, M. and Ohmori, M. (1999) Activation of a cyanobacterial adenylate cyclase, Cya C, by autophosphorylation and subsequent phosphotransfer reaction. *J Biol Chem* 274: 274-15167.

Kehoe, D. M. , and Grossman, A.R. (1996) Similarity of a chromatic adaptation sensor to phytochrome and ethylene receptors. *Science* 273: 273-1409.

Kita, A. , Okajima, K. , Morimoto, Y. , Ikeuchi, M. , and Miki, K. (2005) Structure of a cyanobacterial BLUF protein, Tli0078, containing a novel FAD-binding blue light sensor domain. *J Mol Biol* 349: 349-351.

Kondou, Y. , Mogami, N. , Hoshi, F. , Kutsuna, S. , Nakazawa, M. , Sakurai, T. , Matsui, M. , Kaneko, T. , Tabata, S. , Tanaka, I. , and Manabe, K. (2002) Bipolar localization of putative photoreceptor protein for phototaxis in thermophilic cyanobacterium *Synechococcus elongatus*. *Plant Cell Physiol* 43: 43-1585.

Kondou, Y. , Nakazawa, M. , Higashi, S. , Watanabe, M. , and Manabe, K. (2001) Equal-quantum action spectra indicate fluence-rate-selective action of multiple photoreceptors for photomovement of the thermophilic cyanobacterium *Synechococcus elongatus*. *Photochem Photobiol* 73: 73-90.

Kort, E. N. , Goy, M. F. , Larsen, S. H. , and Adler, J. (1975) Methylation of a membrane protein involved in bacterial chemotaxis. *Proc Natl Acad Sci USA* 72: 72-3939.

Liang, J. , Scappino, L. , and Haselkorn, R. (1992) The patA gene product, which contains a region similar to CheY of *Escherichia coli*, controls heterocyst pattern formation in the cyanobacterium *Anabaena* 7120. *Proc Natl Acad Sci USA* 89: 89-5655.

Lin, L.N. , Li, J. , Brandts, J.F. , and Weis, R.M. (1994) The serine receptor of bacterial chemotaxis exhibits half-site saturation for serine binding. *Biochemistry* 33: 33-6564.

Lounatmaa, K. , Vaara, T. , Osterlund, K. , and Vaara, M. (1980) Ultrastructure of the cell wall of a *Synechocystis* strain. *Rev Can Microbiol* 26: 26-204.

Lux, R. , and Shi, W. (2004). Chemotaxis-guided movements in bacteria. *Cri Rev Oral Biol Med* 15: 15-207.

Masuda, S. , Hasegawa, K. , Ishii, A. , and Ono, T. A. (2004) Light-induced structural changes in a putative blue-light receptor with a novel FAD binding fold sensor of blue-light using FAD (BLUF); Slr1694 of *Synechocystis* sp. PCC6803. *Biochemistry* 43: 43-5304.

Masuda, S. , Hasegawa, K. , Ohta, H. , and Ono, T.A. (2008) Crucial role in light signal transduction for the conserved Met93 of the BLUF protein PixD/Slr1694. *Plant Cell Physiol* 49: 49-1600.

Mattick, J. S. (2002) Type IV pili and twitching motility. *Annu Rev Microbiol* 56: 56-289.

McBride, M. (2000) Bacterial gliding motility: mechanisms and mysteries. *Am Soc Microbiol News* 66: 66-203.

McBride, M.J. (2001) Bacterial gliding motility: Multiple mechanisms for cell movement over surfaces. *Annu Rev Microbiol* 55: 55-69.

McCarren, J. , Heuser, J. , Roth R. , Yamada, N. , Martone, M. , and Brahamsha, B. (2005) Inactivation of SwmA results in the loss of an outer cell layer in a swimming *Synechococcus* strain. *J Bacteriol* 187: 187-224.

Meeks, J. C. , Campbell, E. L. , Summers, M. L. , and Wong, F. C. (2002) Cellular differentiation in the cyanobacterium in *Nostoc punctiforme*. *Arch Microbiol* 178: 178-395.

Merz, A.J. , and Sheetz, S. M. (2000) Pilus retraction powers bacterial twitching motility. *Nature (London)* 407: 407-498.

Moon, Y.-J. , Park, Y. M. , Chung Y.-H. , and Chol, J. S. (2004) Calcium is involved in photomovement of cyanobacterium *Synechocystis* sp. PCC 6803. *Photochem Photobiol* 79: 79-114.

Montgomery, B.L. and Lagarias, J.C. (2002) Phytochrome ancestry: sensors of bilins and light. *Trends Plant Sci* 7: 7-357.

Montgomery, B. L. and Lagarias, J. C. (2002) Phytochrome ancestry: sensors of bilins and light. *Trends Plant Sci* 7: 7-357.

Mullineaux, C. W. (2001) How do cyanobacteria sense and respond to light. *Mol Microbiol* 41: 41-965.

Nakasugi, K. , and Neilan, B.A. (2005) Identification of pilus-like structures and genes in *Microcystis aeruginosa* PCC 7806. *Appl Environ Microbiol* 71: 7621-7625. doi: 10.1128/AEM.71.11.7621-7625.2005

Nakasugi, K. , Alexova, R. , Svenson, C. J. , and Neilan, B. A. (2007) Functional analysis of PilT from the toxic cyanobacterium *Microcystis aeruginosa* PCC 7806. *J Bacteriol* 189: 189-1689.

Nakasugi, K. , Svenson, C. J. , and Neilan, B. A. (2006) The competence gene, comF, from *Synechocystis* sp. strain PCC 6803 is involved in natural transformation, phototactic motility and piliation. *Microbiology* 152: 3623-3631. doi:10.1099/mic.0-29189-0

Ng, W. O. , Grossman, A. R. , and Bhaya, D. (2003) Multiple light inputs control phototaxis in *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 185: 185-1599.

Norling, B. , Zak, E. , Andersson, B. , and Pakrasi, H. (1998) 2D-isolation of pure plasma and thylakoid membranes from the cyanobacterium *Synechocystis* PCC 6803. *FEBS Lett* 436: 436-489.

Nudleman, E. , and Kaiser, D. (2004) Pulling together with Type IV pili. *J Mol Microbiol Biotechnol* 7: 7-52.

Nultsch, W. (1961) Der Einfluss des Lichtes auf die Bewegung der Cyanophyceen. *Planta* 56: 56-632.

Nultsch, W. (1962) Phototaktische Aktionsspektren von Cyanophyceen. *Ber Deutsch Bot Ges* 75: 75-443.

Nultsch, W. , and Schuchart, H. (1985) A model of the phototactic reaction chain of the cyanobacterium *Anabaena variabilis*. *Arch Microbiol* 142: 142-180.

Nultsch, W. , Schuchart, H. , and Koenig, F. (1983) Effects of sodium azide on phototaxis of the blue-green alga *Anabaena variabilis* and consequences to the two-photoreceptor systems-hypothesis. *Arch Microbiol* 134: 134-233.

Ohmori, M. (1989) cAMP in *Anabaena cylindrica*: rapid changes in cellular levels in response to changes in extracellular environments. *Plant Cell Physiol* 30: 30-911.

Ohmori, M. , and Okamoto, S. (2004) Photoresponsive cAMP signal transduction in cyanobacteria. *Photochem Photobiol Sci* 3: 3-503.

Ohmori, M. , Ohmori, K. , and Hasunuma, K. (1988) Rapid change in cyclic-3',5'-AMP concentration triggered by a light-off or light-on signal in *Anabaena cylindrica*. *Arch Microbiol* 150: 150-203.

Ohmori, M. , Terauchi, K. , Okamoto, S. , and Watanabe, M. (1992) Regulation of cAMP-mediated photosignaling by a phytochrome in the cyanobacterium *Anabaena cylindrica*. *Photochem Photobiol* 75: 75-675.

Okajima, K. , Fukushima, Y. , Suzuki, H. , Kita, A. , Ochiai, Y. , Katayama, M. , Shibata, Y. , Miki, K. , Noguchi, T. , Itoh, S. , and Ikeuchi, M. (2006) Fate determination of the flavin photoreceptions in the cyanobacterial blue light receptor TePixD (TII0078). *J Mol Biol* 363: 363-410.

Okajima, K. , Yoshihara, S. , Fukushima, Y. , Geng, X. , Katayama, M. , Higashi, S. , Watanabe, M. , Sato, S. , Tabata, S. , Shibata, Y. , Itoh, S. , and Ikeuchi, M. (2005) Biochemical and functional characterization of BLUF-type flavin-binding proteins of two species of cyanobacteria. *J Biochem* 137: 137-741.

Okamoto, S. , and Ohmori, M. (1999) Analysis of cyanobacterial motility in *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 40 Suppl. 135S.

Okamoto, S. , and Ohmori, M. (2002) The cyanobacterial pil-T protein is responsible for cell motility and transformation hydrolyzes ATP. *Plant Cell Physiol* 43: 43-1127.

Palenik, B. , Brahamsha, B. , Larimer, F.W. , Land, M. , Hauser, L. , Chain, P. , Lamerdin, J. , Regala, W. , Allen, E.E. , McCarren, J. , Paulsen, I. , Dufresne A. , Partensky, F. , Webb, A. , and Waterbury, J. (2003) The genome of a motile marine *Synechococcus*. *Nature (London)* 424: 424-1037.

Park, C. M. , Kim, J. I. , Yang, S. S. , Kang, J. G. , Kang, J. H. , Shim, J. Y. , Chung, Y-H. , Park, Y-M. , and Song, P. S. (2000) A second photochromic bacteriophytochrome from *Synechocystis* sp. PCC 6803: spectral analysis and down-regulation by light. *Biochemistry* 39: 39-10840.

Perkins, F. , Haas, L. , Phillips, D. , and Webb, K. (1981) Ultrastructure of a marine *Synechococcus* possessing spinae. *Can J Microbiol* 27: 27-318.

Pitta, T. P. , and Berg, H. C. (1995) Self-electrophoresis is not the mechanism for motility in swimming cyanobacteria. *J Bacteriol* 177: 177-5701.

Pitta, T. P. , Sherwood, E. E. , Kobel, A. M. , and Berg, H. C. (1997) Calcium is required for swimming by the non-flagellated cyanobacterium *Synechococcus* strain WH8113. *J Bacteriol* 179: 179-2524.

Ramsing, N. B. , Ferris, J. M. , and Ward, D. M. (1997) Light induced motility of thermophilic *Synechococcus* isolates from Octopus Spring, Yellowstone National Park. *Appl Environ Microbiol* 63: 63-2347.

Rockwell, N. C. , and Lagarias, J. C. (2010) A brief history of phytochromes. *Chem Phys Chem* 11: 1172-1180. doi: 10.1000/cphc.200999894

Rockwell, N. C. , Martin, S. S. , Feoktistova, K. , and Lagarias, J. C. (2011) Diverse two-cysteine photocycles in phytochromes and cyanobacteriochromes. *Proc Natl Acad Sci USA* 108: 108-11854.

Rockwell, N. C. , Martin, S. S. , Gulevich, A. G. , and Lagarias, J. C. (2012) Phycoviolobilin formation and spectral tuning in the DXCF cyanobacteriochrome subfamily. *Biochemistry* 51: 51-1449.

Rockwell, N. C. , Shang, L. , Martin, S. S. , and Largaia, J. C. , (2009) Distinct classes of red/far-red photochemistry within the phytochrome superfamily. *Proc Natl Acad Sci USA* 106: 106-6123.

Rockwell, N. C. , Su, Y-S. , and Lagarias, J. C. (2006) Phytochrome structure and signaling mechanisms. *Ann Rev Plant Biol* 57: 57-837.

Samuel, A. D. T. , Petersoen, J. D. , and Reese, T. (2001) Envelope structure of *Synechococcus* sp. WH8113, a non-flagellated swimming cyanobacterium. *BMC Microbiol* 1: 4. doi: 10.1186/1471-2180-1.4.

Sastry, P. A. , Finlay, B. B. , Pasloske, B. L. , Paranchych, W. , Pearlstone, J. R. , and Smille, L. B. (1985) Comparative studies of the amino acid and nucleotide sequences of pilin derived from *Pseudomonas aeruginosa* PAK and PAO. *J Bacteriol* 164: 164-571.

Sastry, P. A. , Pearlstone, J. R. , Smillie, L. B. , and Paranchych, W. (1983) Amino acid sequence of pilin isolated from *Pseudomonas aeruginosa*. *FEBS Lett* 151: 151-253.

Schultze-Lam, S. , and Beveridge, T. J. (1994) Physico-chemical characteristics of the mineral-forming S-layer from the cyanobacterium *Synechococcus* strain GL24. *Can J Microbiol* 40: 40-216.

Smarda, J. D. , Smajs, D. , Komrska, J. , and Krzyzanek, V. (2002) S-layers on cell walls of cyanobacteria. *Micron* 33: 33-257.

Stanier, R. Y. , Kunisawa, R. , Mandel, M. , and Cohen-Bazire, G. (1971) Purification and properties of unicellular blue-green algae (Chroococcales). *Bacteriol Rev* 35: 35-171.

Stock, J. B. , Stock, A. M. , and Motten, J. M. (1990) Signal transduction in bacteria. *Nature (London)* 344: 344-395.

Tanaka, K. , Nakasone, Y. , Okajima, K. , Ikeuchi, M. , Tokutomi, S. , and Terazima, M. (2009) Oligomeric-state-dependent conformational change of the BLUF protein TePixD (TII0078). *J Mol Biol* 386: 386-1290.

Terauchi, K. , and Ohmori, M. (1999) An adenylate cyclase, Cya 1, regulates cell motility in the cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 40: 40-248.

Terauchi, K. , and Ohmori, M. (2004) Blue-light stimulates cyanobacterial motility via a cAMP signal transduction system. *Mol Microbiol* 52: 52-303.

Tyagi, V. V. S. (1976) Studies on phototaxis in the blue-green alga, *Cylindrospermum*. *Biochem Physiol Pflanzen* 170: 170-217.

Vaara, T. (1982) The outermost surface structures in Chroococcalean cyanobacteria. *Rev Can Microbiol* 28: 28-929.

Vaara, T. , and Vaara, M. (1988) Cyanobacterial fimbriae. *Methods Enzymol* 167: 167-189.

Vaara, T. , Ranta, H. , Lounatmaa, K. , and Korhonen, T. K. (1984) Isolation and characterization of pili (fimbriae) from *Synechocystis* CB3. *FEMS Microbiol Lett* 21: 21-329.

Waterbury, J. B. , and Rippka, R. (1989) Order Chroococcales Wettstein 1924. Emend Rippka et al., 1979. *Bergey's Manual of Systematic Bacteriology* Williams and Wilkins, Baltimore, USA. pp. 1728-1746.

Waterbury, J. B. , Willey, J. M. , Franks, D. G. , Valois, F. W. , and Watson, S. W. (1985) A cyanobacterium capable of swimming motility. *Science* 230: 230-274.

Willey, J. M. (1988) Characterization of swimming motility in a marine unicellular cyanobacterium. Ph.D. Thesis. Woods Hole Oceanographic Institution and Massachusetts Institute of Technology, Cambridge, MA, USA.

Willey, J. M. , Waterbury J. B. , and Greenberg, E. P. (1987) Sodium-coupled motility in a swimming cyanobacterium. *J Bacteriol* 169: 169-3429.

Wolgemuth, C. W. , and Oster, G. (2004) The junctional pore complex and the propulsion of bacterial cells. *J Mol Microbiol Biotechnol* 7: 7-72.

Wolgemuth C. , Hoiczky, E. , Kaiser, D. , and Oster, G. (2002) How myxobacteria glide. *Curr Biol* 12: 12-369.

Yeh, K. C. , Wu, S. H. , Murphy, J. T. , and Lagarias, J. C. (1997) A cyanobacterial phytochrome two-component light sensory system. *Science* 277: 277-1505.

Yoshihara, S. , and Ikeuchi, M. (2004) Phototactic motility in the unicellular cyanobacterium *Synechocystis* sp. PCC 6803. *Photochem Photobiol Sci* 3: 3-512.

Yoshihara, S. , Geng, X. , Okamoto, S. , Yura, K. , Murata, T. , Go, M. , Ohmori, M. , and Ikeuchi, M. (2001) Mutational analysis of genes involved in pilus structure, motility and transformation competency in the unicellular motile cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 42: 42-63.

Yoshihara, S. , Geng, X. , and Ikeuchi, M. (2002) pilG Gene cluster and split pilL genes involved in pilus biogenesis, motility and genetic transformation in the cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 43: 43-513.

Yoshihara, S. , Katayama, M. , Geng, X. , and Ikeuchi, M. (2004) Cyanobacterial phytochrome-like PixJ1 holoprotein shows novel reversible photoconversion between blue-and green-absorbing forms. *Plant Cell Physiol* 45: 45-1729.

Yoshihara, S. , Suzuki, F. , Fujita H. , Geng, X. X. , and Ikeuchi, M. (2000) Novel putative photoreceptor and regulatory genes required for the positive phototactic movement of the unicellular motile cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 41: 41-1299.

Yoshimura H. , Hisabori, T. , Yanagisawa, S. , and Ohmori, M. (2000) Identification and characterization of a novel cAMP receptor protein in the cyanobacterium *Synechocystis* sp. PCC 6803. *J Biol Chem* 275: 275-6241.

Yoshimura, H. , Yoshihara, S. , Okamoto, S. , Ikeuchi, M. , and Ohmori, M. (2002) A cAMP receptor protein, SYCRP1, is responsible for the cell motility of *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 43: 43-400.

Yuan, H. , Anderson, S. , Masuda, S. , Dragnea, V. , Moffat, K. , and Bauer, C. (2006) Crystal structures of the *Synechocystis* photoreceptor Slr1694 reveal distinct structural states related to signaling. *Biochemistry* 45: 45-12687.

Circadian Rhythms

Amdaoud, M. , Vallade, M. , Weiss-Schaber, C. , and Mihalcescu, I. (2007) Cyanobacterial clock, a stable phase oscillator with negligible intercellular coupling. *Proc Natl Acad Sci USA* 104: 7051–7056.

Andersson, C. R. , Tsinoremas, N. F. , Shelton, J. , Lebedeva, N. V. , Yarrow, J. , Min, H. , and Golden S. S. (2000) Application of bioluminescence to the study of circadian rhythms in cyanobacteria. *Methods Enzymol* 305: 527–542.

Aoki, S. , Kondo, T. , and Ishiura, M. (1995) Circadian expression of the dnaK gene in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 177: 5606–5611.

Aoki, S. , Kondo, T. , Wada, H. , and Ishiura, M. (1997) Circadian rhythm of the cyanobacterium *Synechocystis* sp. strain PCC 6803 in the dark. *J Bacteriol* 79: 5751–5755.

Arita, K. , Hashimoto, H. , Igari, K. , Akaboshi, M. , Kutsuna, S. , Sato, M. , and Shimizu, T. (2007) Structural and biochemical characterization of a cyanobacterium circadian clock-modifier protein. *J Biol Chem* 292: 1128–1135.

Axmann, I. M. , Dühring, U. , Seeliger, L. , Arnold, A. , Vanselow, T. , Kramer, A. , and Wilde, A. (2009) Biochemical evidence for a timing mechanism in *Prochlorococcus*. *J Bacteriol* 191: 5342–5347. doi:10.1128/JB.00419-09

Bell-Pederson, D. , Cassone, V. M. , Earnest, D. J. , Golden, S. S. , Hardin, P. E. , Thomas, T. L. , and Zoran, M. J. (2005) Circadian rhythms from multiple oscillators: Lessons from diverse organisms. *Nat Rev Genet* 6: 544–556.

Bi, E. F. , and Lutkenhaus, J. (1991) FtsZ ring structure associated with division in *Escherichia coli*. *Nature (London)* 354: 161–164.

Brettschneider, C. , Rose, R. J. , Hertel, S. , Axmann, I. M. , Heck, A. J. R. , and Kollmann, M. (2010) A sequestration feedback governs dynamics and temperature entrainment of the KaiABC circadian clock. *Mol Syst Biol* 6: 389. doi:1038/msb.2010.44

Bünning, E. (1973) *The Physiological Clock* (3rd edn.) Springer-Verlag, New York, NY. USA.

Cervený, J. , and Nedbal, L. (2009) Metabolic rhythms of the cyanobacterium *Cyanothece* sp. ATCC 51142 correlate with modeled dynamics of the circadian clock. *J Biol Rhythms* 24: 295–303.

Chang, Y-G. , Kuo, N-W. , Tseng, R. , and LiWang, A. (2011) Flexibility of the C-terminal, or CII, ring of KaiC governs the rhythm of the circadian clock of cyanobacteria. *Proc Natl Acad Sci USA* 108: 14431–14436. www.pnas.org/cgi/doi/10.1073/pnas.1104221108

Chen, T.-H. , Chen, T.-L. , Huang, L.-M. , and Huang, T.-C. (1991) Circadian rhythm in amino acid uptake by *Synechococcus* RF-1. *Plant Physiol* 97: 55–59.

Chen, T-H. , Pen, S-Y. , and Huang, T-C. (1993) Induction of nitrogen-fixing rhythm *Synechococcus* RF-1 by light signals. *Plant Sci* 92: 179–182.

Chen, Y-B. , Dominic, B. , Mellon, M. T. , and Zehr, J. P. (1998) Circadian rhythm of nitrogenase gene expression in the diazotrophic filamentous nonheterocystous cyanobacterium *Trichodesmium* sp. strain IMS101. *J Bacteriol* 180: 3598–3605.

Clodong, S. , Dühring, U. , Kronk, L. , Wilde, A. , Axmann, I. , Herzel, H. , and Kollmann, M. (2007) Functioning and robustness of a bacterial circadian clock. *Mol Syst Biol* 3: 90.

Corton, J. C. , Ward, Jr., J. E. , and Lutkenhaus, J. (1987) Analysis of cell division gene ftsZ from gram–ve and gram+ve bacteria. *J Bacteriol* 169: 1–7.

Diaz, J. J. , Rhoads, D. D. , and Roufa, D. J. (1991). PCR-mediated chemical mutagenesis of cloned duplex DNAs. *Biotechniques* 11, 204–206, 208, 210–211.

Ditty, J. L. , Canales, S. R. , Anderson, B. E. , Williams, S. B. , and Golden, S. S. (2005) Stability of the *Synechococcus elongatus* PCC 7942 circadian clock under directed anti-phase expression of Kai genes. *Microbiology* 151: 2605–2613.

Ditty, J. L. , Williams, S. B. , and Golden, S. S. (2003) A cyanobacterial circadian timing mechanism. *Annu Rev Genet* 37: 513–543. doi:10.1146/annurev.genet.37.110801.142716

Dolganov, N. , and Grossman, A. R. (1993) Insertional inactivation of genes to isolate mutants of *Synechococcus* sp. strain PCC 7942: Isolation of filamentous mutants. *J Bacteriol* 175: 7644–7651.

Dvornyk, V. (2005) Molecular evolution of *lfpA*, a gene mediating the circadian input signal in cyanobacteria. *J Mol Evol* 60: 105–112.

Dvornyk, V. (2006) Subfamilies of *cpmA*, a gene involved in circadian output, have different evolutionary histories in cyanobacteria. *Microbiology* 152: 75–84.

Dvornyk, V. , Deng, H.-W. , and Nevo, E. (2004) Structure and molecular phylogeny of *SasA* genes in cyanobacteria: Insights into evolution of the prokaryotic circadian system. *Mol Biol Evol* 21: 1468–1476.

Dvornyk, V. , Vinogradova, O. , and Nevo, E. (2002) Long term microclimatic stress causes rapid adaptive radiation of KaiABC clock gene family in a cyanobacterium, *Nostoc linckia* from “Evolution Canyons” I and II, Israel. *Proc Natl Acad Sci USA* 99: 2082–2087.

Dvornyk, V. , Vinogradova, O. , and Nevo, E. (2003) Origin and evolution of circadian clock genes in prokaryotes. *Proc Natl Acad Sci USA* 100: 2495–2500.

Edmunds, L. N., Jr. (1988) *Cellular and Molecular Bases of Biological Clocks*. Springer-Verlag, New York, N. Y. USA.

Egli, M. , Pattanayek, R. , and Pattanayek, S. (2007) Protein-protein interactions in the cyanobacterial KaiABC circadian clock. In: Boeyens, J. C. A. , and Ogilvie, J. F. (Eds.) *Models, Mysteries and Magic of Molecules*. Springer. Dordrecht, The Netherlands. pp. 283–289.

Eguchi, K. , Yoda, M. , Terada, T. P. , and Sasai, M. (2008) Mechanism of robust circadian oscillation of KaiC phosphorylation in vitro. *Biophys J* 95: 1773–1784.

Ehet, C. F. , and Wille, J. J. (1970) The photobiology of circadian rhythms in protozoa and other eukaryotic microorganisms. In: Halldal, P. (Ed.) *Photobiology of Microorganisms*. Wiley, London, UK. pp. 369–416.

Emberly, E. , and Wingreen, N. S. (2006) Hourglass model of a protein based circadian oscillator. *Phys Rev Lett* 96: 038303.

Gallon, J. R. , LaRue, T. A. , and Kurz, W. G. W. (1974) Photosynthesis and nitrogenase activity in the blue-green alga, *Gloeocapsa*. *Can J Microbiol* 20: 1633–1637.

Garces, R. G. , Wu, N. , and Gillon, W. , and Pai, E. F. (2004) Anabaena circadian clock proteins KaiA and KaiB reveal potential common binding site to their partner KaiC. *Embo J* 23: 1688–1698.

Golden, S. S. (2004) Meshing the gears of the cyanobacterial circadian clock. *Proc Natl Acad Sci USA* 101: 13697–13698.

Golden, S. S. , Ishiura, M. , Johnson, C. H. , and Kondo, T. (1997) Cyanobacterial circadian rhythms. *Annu Rev Plant Physiol Plant Mol Biol* 48: 327–354.

Goto, K. , and Johnson, C. H. (1995) Is the cell division cycle gated by a circadian clock? The case of *Chlamydomonas reinhardtii*. *J Cell Biol* 129: 1061–1069.

Grobbelaar, N. , Huang, T.-C. , Lin, H.-Y. , and Chow, T.-J. (1986) Dinitrogen-fixing endogenous rhythm in *Synechococcus* RF-1. *FEMS Microbiol Lett* 37: 173–177.

Hayashi, F. , Itoh, N. , Uzumaki, T. , Iwase, R. , Tsuchiya, Y. , Yamakawa, H. , Morishita, M. , Onai, K. , Itoh, S. , and Ishiura, M. (2004) Roles of two ATPase motif containing domains in cyanobacterial clock protein KaiC. *J Biol Chem* 279: 52321–52337.

Hayashi, F. , Iwase, R. , Uzumaki, T. , and Ishiura, M. (2006) Hexamerization by the N-terminal domain and intersubunit phosphorylation by the C-terminal domain of cyanobacterial circadian clock protein KaiC. *Biochem Biophys Res Commun* 318: 864–872.

Hayashi, F. , Suzuki, H. , Iwase, R. , Uzumaki, T. , Miyake, A. , Shen, J.-R. , Imada, K. , Furukawa, Y. , Yonemura, K. , Namba, K. , and Ishiura, M. (2003) ATP-induced hexameric ring structure of the cyanobacterial circadian clock protein KaiC. *Genes to Cells* 8: 287–296.

Hitomi, K. , Oyama, T. , Han, S. , Arvai, A. S. , and Getzoff, E. D. (2005) Tetrameric architecture of the circadian clock protein KaiB. *J Biol Chem* 280: 19127–19135.

Holtzendorff, J. , Partensky, F. , Mella, D. , Lennon, T.-F. , Hess, W. R. , and Garczarek, L. (2008) Genome streamlining results in loss of robustness of the circadian clock in the marine cyanobacterium *Prochlorococcus marinus* PCC 9511. *J Biol Rhythms* 23: 187–199.

Huang, T.-C. , and Chow, T.-J. (1986) New type of N₂ fixing unicellular cyanobacterium (blue-green alga). *FEMS Microbiol Lett* 36: 109–110.

Huang, T.-C. , and Grobbelaar, N. (1995) The circadian clock in the prokaryote *Synechococcus* RF-1. *Microbiology* 141: 535–540.

Huang, T.-C. , and Chou, W.-M. (1991) Setting of the circadian N₂ -fixing rhythm of the prokaryotic *Synechococcus* sp. RF-1 while its *nif* gene is repressed. *Plant Physiol* 96: 324–326.

Huang, T.-C. , Chen, H.-M. , Pen, S.-Y. , and Chen, T.-H. (1994) Biological clock in the prokaryote *Synechococcus* RF-1. *Planta* 193: 131–136.

Huang, T.-C. , Tu, J. , Chow, T.-J. , and Chen, T.-H. (1990) Circadian rhythm of the prokaryote *Synechococcus* sp. RF-1. *Plant Physiol* 92: 531–533.

Huang, T.-C. , Wang, S.-T. , and Grobbelaar, N. (1993) Circadian rhythm mutants of the prokaryotic *Synechococcus* RF-1. *Curr Microbiol* 27: 249–254.

Imai, K. , Nishiwaki, T. , Kondo, T. , and Iwasaki, H. (2004) Circadian rhythms in the synthesis and degradation of master protein KaiC in the cyanobacteria. *J Biol Chem* 279: 36534–36539.

Ishiura, M. , Kutsuna, S. , Aoki, S. , Iwasaki, H. , Andersson C. R. , Tanabe, A. , Golden S. S. , Johnson, C. H. , and Kondo, T. (1998) Expression of a gene cluster KaiABC as a circadian feedback process in cyanobacteria. *Science* 281: 1519–1523.

Ito, H. , Kageyama, H. , Mutsuda, M. , Nakajima, M. , Oyama, T. , and Kondo, T. (2007) Autonomous synchronization of the circadian KaiC phosphorylation rhythm. *Nat Struct Mol Biol* 14: 1084–1088.

Ivleva, N. B. , Bramlett, M. R. , Lindahl, P. A. , and Golden, S. S. (2005) *LdpA*: a component of the circadian clock senses redox state of the cell. *Embo J* 24: 1202–1210.

Ivleva, N. B. , Gao, T. , LiWag, A. C. , and Golden, S. S. (2006) Quinone sensing by the circadian input kinase of the cyanobacterial circadian clock. *Proc Natl Acad Sci USA* 103: 17468–17473.

Iwasaki, H. , and Kondo, T. (2004) Circadian timing mechanism in the prokaryotic clock system of cyanobacteria. *J Biol Rhythms* 19: 436–444.

Iwasaki, H. , Taniguchi, Y. , Ishiura, M. , and Kondo, T. (1999) Physical interactions among circadian clock proteins, KaiA, KaiB and KaiC, in cyanobacteria. *Embo J* 18: 1137–1145.

Iwasaki, H. , Williams, S. B. , Kitayama, Y. , Ishiura, M. , Golden, S. S. , and Kondo, T. (2000) A KaiC-interacting sensory histidine kinase SasA, necessary to sustain robust circadian oscillation in cyanobacteria. *Cell* 101: 223–233.

Iwasaki, H. , Nishiwaki, T. , Kitayama, Y. , Kakajima, M. , and Kondo, T. (2002) KaiA-stimulated KaiC phosphorylation in circadian timing loops in cyanobacteria. *Proc Natl Acad Sci USA* 99: 15788–15793.

Iwase, R. , Imada, K. , Hayashi, F. , Uzumaki, T. , Namba, K. , and Ishiura, M. (2004) Crystallization and preliminary crystallographic analysis of the circadian clock protein KaiB from the thermophilic cyanobacterium *Thermosynechococcus elongatus* BP-1. *Acta Crystallogr D* 60: 727–729.

Iwase, R. , Imada, K. , Hayashi, F. , Uzumaki, T. , Morishita, M. , Onai, K. , Furukawa, Y. , Namba, K. , and Ishiura, M. (2005) Functionally important substructures of circadian protein KaiB in a unique tetramer complex. *J Biol Chem* 280: 43141–43149.

Johnson, C. H. (1995) Photobiology of circadian rhythms. In: Horspool, W. M. , and Song, P.-S. (Eds.) *CRC Handbook of Organic Photochemistry and Photobiology*. CRC Press, Boca Raton, Florida, FL, USA. pp. 1602–1610.

Johnson, C. H. (2004) Global orchestration of gene expression by the biological clock of cyanobacteria. *Genome Biology* 5: 217. <http://genomebiology.com/2004/5/217>

Johnson, C. H. (2004) Precise circadian clocks in cyanobacteria. *Curr Issues Mol Biol* 6: 103–110.

Johnson, C. H. (2010) Circadian clocks and cell division. What's the pacemaker? *Cell Cycle* 9: 3864–3873. doi:10.4161/cc.9.19.13205

Johnson, C. H. , and Golden, S. S. (1999) Circadian programs in cyanobacteria: Adaptiveness and mechanism. *Annu Rev Microbiol* 53: 389–409.

Johnson, C. H. , Egli, M. , and Stewart, P. C. (2008a) Structural insights into a circadian oscillator. *Science* 322: 697–701.

Johnson, C. H. , Golden, S. S. , and Kondo, T. (1998) Adaptive significance of circadian programs in cyanobacteria. *Trends Microbiol* 6: 407–410.

Johnson, C. H. , Golden, S. S. , Ishiura, M. , and Kondo, T. (1996) Circadian clocks in prokaryotes. *Mol Microbiol* 21: 5–11.

Johnson, C. H. , Mori, T. , and Xu, Y. (2008b) A cyanobacterial circadian clockwork. *Curr Biol* 18: 816–825. doi:10.1016/j.cub.2008.07.012

Johnson, C. H. , Stewart, P. L. , and Egli, M. (2011) The cyanobacterial circadian system: From biophysics to bioevolution. *Annu Rev Biophys* 40: 143–167.

Kageyama, H. , Kondo, T. , and Iwasaki, H. (2003) Circadian formation of clock protein complexes by KaiA, KaiB, KaiC and SasA in cyanobacteria. *J Biol Chem* 278: 2388–2395.

Kageyama, H. , Nishiwaki, T. , Nakajima, M. , Iwasaki, H. , Oyama, T. , and Kondo, T. (2006) Cyanobacterial circadian pacemaker: Kai protein complex dynamics in the KaiC phosphorylation cycle in vitro. *Mol Cell* 23: 161–171. doi:10.1016/j.molcel.2006.05.039

Kaneko, T. , Sato, S. , Kotani, H. , Tanaka, A. , Asamizu, E. , Nakamura, Y. , Miyajima, N. , Hirose, M. , Sugiura, M. , Sasamoto, S. , Kimura, T. , Hosouchi, T. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Naruo, K. , Okumura, S. , Shimpo, S. , Takeuchi, C. , Wada, T. , Watanabe, A. , Yamada, M. , Yasuda, M. , and Tabata, S. (1996) Sequence analysis of the genome of the unicellular cyanobacterium *Synechocystis* sp. strain PCC 6803. II. Sequence determination of the entire genome and assignment of potential protein-coding regions. *DNA Res* 3: 109–136.

Katayama, M. , Kondo, T. , Xiong, J. , and Golden, S. S. (2003) IcpA Encodes an iron-sulfur protein involved in light-dependent modulation of the circadian period in the cyanobacterium *Synechococcus elongatus* PCC 7942. *J Bacteriol* 185: 1415–1422.

Katayama, M. , Tsinoremas, N. F. , Kondo, T. , and Golden, S. S. (1999) cpmA, a gene involved in an output pathway of the cyanobacterial circadian system. *J Bacteriol* 181: 3516–3524.

Kim, Y.-I. , Dong, G. , Carruthers Jr., C. W. , Golden, S. S. , and Liwang, A. (2008) The day/night switch in KaiC, a central oscillator component of the circadian clock of cyanobacteria. *Proc Natl Acad Sci USA* 105: 12825–12830.

Kitayama, Y. , Iwasaki, H. , Nishiwaki, T. , and Kondo, T. (2003) KaiB functions as an attenuator of KaiC phosphorylation in the cyanobacterial clock system. *Embo J* 22: 2127–2134.

Kitayama, Y. , Nishiwaki, T. , Terauchi, K. , and Kondo, T. (2008) Dual KaiC-based oscillations constitute the circadian system of cyanobacteria. *Genes Dev* 22: 1513–1521.

Kiyohara, Y. B. , Katayama, M. , and Kondo, T. (2005) A novel mutation of KaiC affects resetting of the cyanobacterial circadian clock. *J Bacteriol* 187: 2559–2564.

Klevecz, R. R. (1976) Quantized generation time in mammalian cells as an expression of the cellular clock. *Proc Natl Acad Sci USA* 73: 4012–4016.

Kondo, T. , and Ishiura, M. (1994) Circadian rhythms of cyanobacteria: monitoring the biological clocks of individual colonies by bioluminescence. *J Bacteriol* 176: 1881–1885.

Kondo, T. , Strayer, C. A. , Kukarni, D. , Taylor, W. , Ishiura, M. , Golden, S. S. , and Johnson, C. H. (1993) Circadian rhythms in prokaryotes: luciferase as a reporter of circadian gene expression in cyanobacteria. *Proc Natl Acad Sci USA* 90: 5672–5676.

Kondo, T. , Tsinoremas, N. F. , Golden, S. S. , Johnson, C. H. , Kutsuna, S. , and Ishiura, M. (1994) Circadian clock mutants of cyanobacteria. *Science* 266: 1233–1236.

Kucho, K. , Tsuchiya, Y. , Okumoto, Y. , Harada, M. , Yamada, M. , and Ishiura, M. (2004b) Construction of unmodified oligonucleotide-based microarrays in the thermophilic cyanobacterium *Thermosynechococcus elongatus* BP-1: screening of the candidates for circadianly expressed genes. *Genes Genet Syst* 79: 319–329.

Kucho, K. , Okamoto, K. , Tsuchiya, Y. , Nomura, S. , Nango, M. , Kanehisa, M. , and Ishiura, M. (2005) Global analysis of circadian expression in the cyanobacterium *Synechocystis* sp. strain PCC6803. *J Bacteriol* 187: 2190–2199.

Kucho, K. , Yoneda, H. , Harada, M. , and Ishiura, M. (2004a) Determinants of sensitivity and specificity in spotted DNA microarrays with unmodified oligonucleotides. *Genes Genet Syst* 79: 189–197.

Kurosawa, G. , Aihara, K. , and Iwasa, Y. (2006) A model for the circadian rhythm of cyanobacteria that maintains oscillation without gene expression. *Biophys J* 91: 2015–2023.

Kutsuna, S. , Kondo, T. , Aoki, S. , and Ishiura, M. (1998) A period-extender gene, pex, that extends the period of the circadian clock in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 180: 2167–2174.

Kutsuna, S. , Nakahira, Y. , Katayama, M. , Ishiura, M. , and Kondo, T. (2005) Transcriptional regulation of the circadian clock operon KaiBC by upstream regions in cyanobacteria. *Mol Microbiol* 57: 1474–1484.

Leipe, D.D. , Aravind, L. , Grishin, N.V. and Koonin, E.V. (2000) The bacterial replicative helicase DnaB evolved from a RecA duplication. *Genome Res* 10: 5–16.

Li, C. , Chen, X. , Wang, P. , and Wang, W. (2009) Circadian KaiC phosphorylation. A multilayer network. PLoS Comput Biol 5: e1000568. doi: 10.1371/journal.pcbi.1000568.

Li, R. , and Golden, S. S. (1993) Enhancer activity of light-responsive regulatory elements in the untranslated leader regions of cyanobacterial psbA genes. Proc Natl Acad Sci USA 90: 11678–11682.

Liu, Y. , Golden, S. S. , Kondo, T. , Ishiura, M. , and Johnson, C. H. (1995a) Bacterial luciferase as a reporter gene expression in cyanobacteria. J Bacteriol 177: 2080–2086.

Liu, Y. , Tsinoremas, N. F. , Johnson, C. H. , Lebedeva, N. V. , Golden, S. S. , Ishiura, M. , and Kondo, T. (1995b) Circadian orchestration of gene expression in cyanobacteria. Genes Dev 9: 1469–1478.

Liu, Y. , Tsinoremas, N. F. , Golden, S. S. , Kondo, T. , and Johnson, C. H. (1996) Circadian expression of genes involved in the purine biosynthetic pathway of the cyanobacterium *Synechococcus* sp. strain PCC 7942. Mol Microbiol 20: 1071–1081.

Lorne, J. , Scheffer, J. , Lee, A. , Painter, M. , and Miao, V. P. W. (2000) Genes controlling circadian rhythm are widely distributed in cyanobacteria. FEMS Microbiol Lett 189: 129–133.

Lozza-Correa, M. , Gomez-Valero, L. , and Buchrieser, C. (2010) Circadian clock proteins in prokaryotes: hidden rhythms? Frontiers Microbiol doi: 10.3388/fmicb.2010.00130

Mackey, S. R. , Choi, J.-S. , Kitayama, Y. , Iwasaki, H. , Dong, G. , and Golden, S. S. (2008) Proteins found in CikA interaction assay link the circadian clock, metabolism and cell division in *Synechococcus elongatus*. J Bacteriol 190: 3738–3746.

Mackey, S. R. , Ditty, J. L. , Clerico, E. M. , and Golden, S. S. (2005) Detection of rhythmic bioluminescence from luciferase reporters in cyanobacteria. In: Rosato, E. (Ed.) Circadian Rhythms: Methods and Protocols. Methods in Molecular Biology 328: 115–129. Humana Press, Totowa, N. J., USA. doi:10.1007/978-1-59745-257-1_8

Matsuda, M. , Michel, K.-P. , Zhang, X. , Montgomery, B. L. , and Golden, S. S. (2003) Biochemical properties of CikA an unusual phytochrome-like histidine protein kinase that resets the circadian clock in *Synechococcus elongatus* PCC 7942. J Biol Chem 278: 19102–19110.

McClung, C. R. (2007) The cyanobacterial circadian clock is based on the intrinsic ATPase activity. Proc Natl Acad Sci USA 104: 16727–16728.

Mehra, A. , Hong, C. I. , Shi, M. , Loros, J. J. , Dunlap, J. C. and, Ruoff, P. (2006) Circadian rhythmicity by autocatalysis. PLoS Comput Biol 2: e96

Millineaux, P. M. , Gallon, J. R. , and Chaplan, A. E. (1981) Acetylene reduction (nitrogen fixation) by cyanobacteria grown under alternating light-dark cycles. FEMS Microbiol Lett 10: 245–247.

Mihalcescu, I. , Hsing, W. , and Leibler, S. (2004) Resilient circadian oscillator revealed in individual cyanobacteria. Nature (London) 430: 81–85.

Min, H. , and Golden, S. S. (2000) A new circadian Class-2 gene, *opcA*, whose product is important for reductant production at night in *Synechococcus elongatus* PCC 7942. J Bacteriol 182: 6214–6221.

Min, H. , Liu, Y. , Johnson, C. H. , and Golden, S. S. (2004) Phase determination of circadian gene expression in *Synechococcus elongatus* PCC 7942. J Biol Rhythms 19: 103–112.

Mitsui, A. , Kumazawa, S. , Takahashi, A. , Ikemoto, H. , and Arai, T. (1986) Strategy by which nitrogen-fixing unicellular cyanobacteria grow photoautotrophically. Nature (London) 323: 720–722.

Miyoshi, F. , Nakayama, Y. , Kaizu, K. , Iwasaki, H. , and Tomita, M. (2007) A mathematical model for the Kai-protein-based chemical oscillator and clock gene expression rhythms in cyanobacteria. J Biol Rhythms 22: 69–80. doi:10.1177/0748730406295749.

Mackey, S. R. , Ditty, J. L. , Clerico, E. M. , and Golden, S. S. (2007) Detection of rhythmic luminescence from luciferase reporters in cyanobacteria. In: Rosato, E. (Ed.) Circadian Rhythms: Methods and Protocols. Methods in Molecular Biology 362. Humana Press, Totowa, N. J. USA.

Mori, T. , and Johnson, C. H. (2001a) Circadian programming in cyanobacteria. Seminar Cell Dev Biol 18: 7235–7242.

Mori, T. , and Johnson, C. H. (2001b) Independence of circadian timing from cell division in cyanobacteria. J Bacteriol 183: 2439–2444.

Mori, T. , Binder, B. , and Johnson, C. H. (1996) Circadian gating of cell division in cyanobacteria growing with average doubling times of less than 24 h. Proc Natl Acad Sci USA 93: 10183–10188.

Mori, T. , Saveliev, S. V. , Xu, Y. , Stafford, W. F. , Cox, M. M. , Inman, R. B. , and Johnson, C. H. (2002) Circadian clock protein KaiC forms ATP-dependent hexameric rings and binds DNA. Proc Natl Acad Sci USA 99: 17203–17208.

Mori, T. , Williams, D. R. , Byrne, M. O. , Qin, X. , Egli, M. , Machab, H. S. , Stewart, P. L. , and Johnson, C. H. (2007) Elucidating the ticking of an in vitro circadian clock work. PLoS Biol 5: e93. doi:10.1371/journal.pbio.0050093.

Naef, F. (2005) Circadian clocks go in vitro: Purely post-translational oscillators in cyanobacteria. Mol Syst Biol doi:10.1038/msb4100027-E1-E5.

Nair, U. , Ditty, J. L. , Min, H. , and Golden, S. S. (2002) Roles for sigma factors in global circadian regulation of the cyanobacterial genome. J Bacteriol 184: 3530–3538.

Nakajima, M. , Imai, K. , Ito, H. , Nishiwaki, T. , Murayama, Y. , Iwasaki, H. , Oyama, T. , and Kondo, T. (2005) Reconstitution of circadian oscillation of cyanobacterial KaiC phosphorylation in vitro. Science 308: 414–415.

Nakajima, M. , Ito, H. , and Kondo, T. (2010) In vitro regulation of circadian phosphorylation rhythm of cyanobacterial clock protein KaiC by KaiA and KaiB. FEBS Lett 584: 898–902.

Nakahira, Y. , Katayama, M. , Miyashita, H. , Kutsuna, S. , Iwasaki, H. , Oyama, T. , and Kondo, T. (2004) Global gene expression by KaiC as a master process of prokaryotic circadian system. Proc Natl Acad Sci USA 101: 881–885.

Narusaka, Y. , Narusaka, M. , Satoh, K. , and Kobayashi, H. (1999) In vitro random mutagenesis of the D1 protein of the photosystem II reaction center confers phototolerance on the cyanobacterium *Synechocystis* sp. PCC 6803. J Biol Chem 274: 23270–23275.

Nishimura, H. , Nakahira, Y. , Imai, K. , Tsuruhara, A. , Kondo, H. , Hayashi, H. , Hirai, M. , Saito, H. , and Kondo, T. (2002) Mutations in KaiA, a clock protein, extend the period of circadian rhythm in the cyanobacterium *Synechococcus elongatus* PCC 7942. Microbiology 148: 2903–2909.

Nishiwaki, T. , Iwasaki, H. , Ishiura, M. , and Kondo, T. (2000) Nucleotide binding and autophosphorylation of clock protein KaiC as a circadian timing process of cyanobacteria. Proc Natl Acad Sci USA 97: 495–499.

Nishiwaki, T. , Satomi, Y. , Nakajima, M. , Lee, C. , Kiyohara, R. , Kageyama, H. , Kitayama, Y. , Temamoto, M. , Yamaguchi, A. , Hajikata, A. , Go, M. , Iwasaki, H. , Takao, T. , and Kondo, T. (2004) Role of KaiC phosphorylation in the circadian clock system of *Synechococcus elongatus* PCC 7942. Proc Natl Acad Sci USA 101: 13927–13932.

Onai, K. , Morishita, M. , Itoh, S. , Okamoto, K. , and Ishiura, M. (2004) Circadian rhythms in the thermophilic cyanobacterium *Thermosynechococcus elongatus*, compensation of period length over a wide temperature range. *J Bacteriol* 186: 4972–4977.

Ouyang, Y. , Andersson, C. R. , Kondo, T. , Golden, S. S. , and Johnson, C. H. (1998) Resonating circadian clocks enhance fitness in cyanobacteria. *Proc Natl Acad Sci USA* 95: 8660–8664.

Paranjpe, D. A. , and Sharma, V. K. (2005) Evolution of temporal order in living organisms. *J Circadian Rhythms* 3: 7. doi:10.1186.1740-3391-3-7

Pattanayek, R. , Wang, J. , Mori, T. , Xu, Y. , Johnson, C. H. , and Egli, M. (2004) Circadian clock protein: Crystal structure of KaiC protein and functional insights. *Mol Cell* 15: 375–388.

Pattanayek, R. , Williams, D. R. , Pattanayek, S. , Mori, T. , Johnson, C. H. , Stewart, P. L. , and Egli, M. (2008) Structural model of the circadian clock KaiB-KaiC complex and mechanism for modulation of KaiC phosphorylation. *Embo J* 27: 1767–1778.

Pettersen, E. F. , Goddard, T. D. , Huang, C. C. , Couch, G. S. , Greenblatt, D. M. , Meng, E. C. , and Ferrin, T. E. (2004) UCSF-Chimera—a visualization system for exploratory research and analysis. *J Comput Chem* 13: 1605–1612.

Qin, X. , Byrne, M. , Xu, Y. , Mori, T. , and Johnson, C. H. (2010) Coupling of a core post-translational pacemaker to a slave transcription/translation feedback loop in a circadian system. *PLoS Biol* 8: e1000394.

Qin, X. , Byrne, M. , Mori, T. , Zon, P. , Williams, D. R. , Mchaourab, H. , and Johnson, C. H. (2010) Intermolecular associations determine the dynamics of the circadian oscillations in vitro. *Proc Natl Acad Sci USA* 107: 14805–14810.

Roenneberg, T. , and Foster, R.G. (1997) Twilight times: light and circadian system. *Photochem Photobiol* 66: 549–561.

Rust, M. J. , Markson, J. S. , Lane, W. S. , Fisher, D. S. , and O'Shea, E. K. (2007) Ordered phosphorylation governs oscillation of a three-protein circadian clock. *Science* 318: 809–812.

Schmitz, O. , Williams, S. B. , Katayama, M. , Kondo, T. , and Golden, S. S. (2000) CikA, a bacteriophytochrome that resets the cyanobacterial circadian clock. *Science* 289: 765–768.

Schneegurt, M. A. , Sherman, D. M. , Nayar, S. , and Sherman, L. A. (1994) Oscillating behaviour of carbohydrate granule formation and dinitrogen fixation in the cyanobacterium *Cyanothece* sp. strain ATCC 51142. *J Bacteriol* 176: 1586–1597.

Schneegurt, M. A. , Sherman, D. M. , and Sherman, L. A. (1997) Growth, physiology, and ultrastructure of a diazotrophic cyanobacterium, *Cyanothece* sp. strain ATCC 51142, in mixotrophic and chemoheterotrophic cultures. *J Phycol* 33: 632–642.

Smith, R. M. , and Williams, S. B. (2006) Circadian rhythms in gene transcription imparted by chromosome compaction in the cyanobacterium *Synechococcus elongatus*. *Proc Natl Acad Sci USA* 103: 8564–8569. doi/10.1073/pnas.0508696103

Stal, L. J. , and Krumbein, W. E. (1985) Nitrogenase activity in the non-heterocystous cyanobacterium *Oscillatoria* sp. grown under alternating light-dark cycles. *Arch Microbiol* 143: 67–71.

Stoeckel, J. , Welsh, E. A. , Liberton, M. , Kunnvakkam, R. , Aurora, R. , and Pakrasi, H. B. (2008) Global transcriptomic analysis of *Cyanothece* 51142 reveals robust diurnal oscillation of central metabolic processes. *Proc Natl Acad Sci USA* 105: 6156–6161.

Sweeney, B. M. , and Borgese, M. B. (1989) A circadian rhythm in cell division in a prokaryote, the cyanobacterium *Synechococcus* WH7803. *J Phycol* 25: 183–186.

Takai, N. , Nakajima, M. , Oyama, T. , Kito, R. , Sugita, C. , Sugita, M. , Kondo, T. , and Iwasaki, H. (2006) A KaiC associating SasA-RpaA two component regulatory system as a major circadian timing mediator in cyanobacteria. *Proc Natl Acad Sci USA* 103: 12109–12114.

Takigawa-Imamura, H. , and Mochizuki, A. (2006) Predicting regulation of the phosphorylation cycle of KaiC clock protein using mathematical analysis. *J Biol Rhythms* 21: 405–416.

Taniguchi, Y. , Katayama, M. , Ito, R. , Takai, N. , Kondo, T. , and Oyama, T. (2007) labA : a novel gene required for negative feed back regulation of the cyanobacterial circadian clock protein KaiC. *Genes Dev* 21: 60–70.

Terauchi, K. , Kitayama, Y. , Nishiwaki, T. , Miwa, K. , Murayama, Y. , Oyama, T. , and Kondo, T. (2007) ATPase activity of KaiC determines the basic timing for circadian clock of cyanobacteria. *Proc Natl Acad Sci USA* 104: 16377–16381.

Taniguchi, Y. , Yamaguchi, A. , Hijikata, A. , Iwasaki, H. , Kamagata, K. , Ishiura, M. , Go, M. , and Kondo, T. (2001) Two KaiA binding domains of cyanobacterial circadian clock protein KaiC. *FEBS Lett* 496: 86–90.

Tomita, J. , Nakajima, M. , Kondo, T. , and Iwasaki, H. (2005) No transcription-translation feedback in circadian rhythm of KaiC phosphorylation. *Science* 307:251–254.

Tsinoremas, N. F. , Ishiura, M. , Kondo, T. , Andersson, C. R. , and Tanaka, K. (1996) A sigma factor that modifies the circadian expression of a subset of genes in cyanobacteria. *Embo J* 15: 2488–2495.

Tsinoremas, N. F. , Schaefer, M. R. , and Golden, S. S. (1994) Blue and red light reversibly control psbAI expression in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Biol Chem* 269: 16143–16147.

Uzumaki, T. , Fujita, M. , Nakatsu, T. , Hayashi, F. , Shibata, H. , Itoh, N. , Kato, H. , and Ishiura, M. (2004) Crystal structure of the C-terminal clock-oscillator domain of the cyanobacterial KaiA protein. *Nat Struct Mol Biol* 11: 623–631.

Vakonakis, I. , and LiWang, A. C. (2004) Structure of the C-terminal domain of the clock protein KaiA in complex with a KaiC-derived peptide: Implications for KaiC regulation. *Proc Natl Acad Sci USA* 101: 10925–10930.

Vakonakis, I. , Klewer, D. A. , Williams, S. B. , Golden, S. S. , and LiWang, A. (2004a) Structure of the N-terminal domain of the circadian clock-associated histidine kinase SasA. *J Mol Biol* 342: 9–17.

Vakonakis, I. , Sun, J. , Wu, T. , Holzenburg, A. , Golden, S. S. , and LiWang, A.C. (2004b) NMR-structure of the Kai C-terminal domain of KaiA, a circadian clock protein: Implications for KaiA-KaiC interaction. *Proc Natl Acad Sci USA* 101: 1479–1484.

van Zon, J. S. , Lubensky, D. K. , Altena, P. R. H. , Rein ten Wolde, P. (2007) An allosteric model of circadian KaiC phosphorylation. *Proc Natl Acad Sci USA* 104: 7420–7425. doi:10.1073/pnas.0608665104

Weare, N. M. , and Benemann, J. R. , (1974) Nitrogenase activity and photosynthesis in *Plectonema boryanum*. *J Bacteriol* 119: 258–265.

Williams, S. B. , Vakonakis, I. , Golden, S. S. , and Li Wang, A. C. (2002) Structure and function from the circadian clock protein KaiA of *Synechococcus elongatus*: A potential clock input mechanism. *Proc Natl Acad Sci USA* 99: 15357–15362.

Woelfle, M. A. , and Johnson, C. H. (2006) No promoter left behind: Global circadian gene expression in cyanobacteria. *J Biol Rhythms* 21: 419–431. doi:10.1127/0748730406294418

Woelfle, M. A. , Ouyang, Y. , Phanvijhitsiri, K. , and Johnson, C. H. (2004) The adaptive value of circadian clocks: An experimental assessment in cyanobacteria. *Curr Biol* 14: 1481–1486.

Woelfle, M. A. , Xu, Y. , Qin, X. , and Johnson, C. H. (2007) Circadian rhythms of superhelical status of DNA in cyanobacteria. *Proc Natl Acad Sci USA* 104: 18819–18824.

Wolk, C. P. , Cai, Y. , and Panoff, J-M. (1991) Use of transposon with luciferase as a reporter to identify environmentally responsive genes in a cyanobacterium. *Proc Natl Acad Sci USA* 88: 5355–5359.

- Xu, Y. , Mori, T. , and Johnson, C. H. (2000) Circadian clock-protein expression in cyanobacteria: Rhythms and phase setting. *Embo J* 19: 3349–3357.
- Xu, Y. , Mori, T. , and Johnson, C. H. (2003) Cyanobacterial circadian clockwork: Roles of KaiA, KaiB, and the KaiBC promoter in regulating KaiC. *Embo J* 22: 2117–2126.
- Xu, Y. , Mori, T. , Pattanayek, R. , Pattanayek, S. , Egli, M. , and Johnson, C. H. (2004) Identification of key phosphorylation sites in the circadian clock protein KaiC by crystallographic and mutagenic analysis. *Proc Natl Acad Sci USA* 101: 13933–13938.
- Xu, Y. , Mori, T. , Qin, X. , Yan, H. , Egli, M. , and Johnson, C. H. (2009) Intramolecular regulation of phosphorylation status of the circadian clock protein KaiC. *PLoS ONE* 4: e7509. doi:10.1371/journal.pone.0007509
- Xu, Y. , Piston, D. , and Johnson, C. H. (1999) A bioluminescence resonance energy transfer (BRET) system—application to interacting circadian clock proteins. *Proc Natl Acad Sci USA* 96: 15–16.
- Ye, S. , Vakonakis, I. , Ioerger, T. R. , LiWang, A. C. , and Sacchettini, J. C. (2004) Crystal structure of circadian clock protein KaiA from *Synechococcus elongatus*. *J Biol Chem* 279: 20511–20518.
- Yoda, M. , Eguchi, K. , Terada, T. P. , and Sasai, M. (2007) Monomer-shuffling and allosteric transition in KaiC circadian oscillation. *PLoS ONE* 2: e408. doi:10.1371/journal.pone.0000408
- Zhang, X. , Dong, G. , and Golden, S. S. (2006) The pseudo-receiver domain of CikA regulates the cyanobacterial circadian input pathway. *Mol Microbiol* 60: 658–668.
- Zwicker, D. , Lubensky, D. K. , and Rein ten Wolde, P. (2010) Robust circadian clocks from coupled protein-modification and transcription-translation cycles. *Proc Natl Acad Sci USA Early Edition* doi: 10.1073/pnas.1007613107

Symbiosis

- Adams, D. G. (2000) Symbiotic interactions. In: Whitton, B. A. , and Potts, M. (Eds.) *Ecology of Cyanobacteria: Their Diversity in Time and Space*. Kluwer Academic, Dordrecht, The Netherlands. pp. 523-561.
- Adams, D. G. , and Duggan, P. S. (2008) Cyanobacteria-bryophyte symbioses. *J Exp Bot* 59: 1047-1058. doi:10.1093/jxb/em.005.
- Ahmadjian, V. (1967) A guide to the algae occurring as lichen symbionts: Isolation, culture, cultural physiology, and identification. *Phycologia* 6: 6-127.
- Ahmadjian, V. (1987) Coevolution in lichens. *Ann New York Acad Sci* 503: 503-507.
- Ahmadjian, V. (1989) Studies on the isolation and synthesis of bionts of the cyanolichen *Peltigera canina* (Peltigeraceae). *Plant Syst Evol* 165: 165-229.
- Ahmadjian, V. (1993) *The Lichen Symbiosis*. John Wiley & Sons, New York, NY, USA.
- Alberte, R. S. , Cheng, L. , and Lewin, R. A. (1987) Characteristics of *Prochloron*-ascidian symbioses. 2. Photosynthesis irradiance relationships and carbon balance of association from Palau Micronesia. *Symbiosis* 4: 4-147.
- Albrecht, C. , Geurts, R. , and Bisseling, T. (1999) Legume nodulation and mycorrhizae formation: Two extremes in host specificity meet. *Embo J* 18: 18-281.
- Antoine, M. E. (2004) An ecophysiological approach for quantifying nitrogen fixation by *Lobaria oregana*. *Bryologist* 107: 107-182.
- Armaleo, D. , and Clerc, P. (1991) Lichen Chimeras: DNA analysis suggests that one fungus forms two morphotypes. *Exptl Mycol* 15: 15-21.
- Arntz, C. , and Tudzynski, P. (1997) Identification of genes induced in alkaloid-producing cultures of *Claviceps* sp. *Curr Genet* 31: 31-357.
- Arsenault, A. , and Goward, T. (2000) The drip zone effect: New insights into the distribution of rare lichens. In: Darling, L. M. (Ed.) *Proc Biology and Management of Species and Habitats at Risk* 2: 767-768. Ministry of Environment, Lands and Parks, Victoria, B. C. and University College of the Cariboo, Kamloops, B. C.
- Arve, E. , Dimitra, P. , Eli Helene, R. , and Anton, L. (2008) Phylogenetic patterns among *Nostoc* cyanobionts within bi- and tripartite lichens of the genus *Pannaria*. *J Phycol* 44: 44-1049.
- Bachereau, F. , and Asta, J. (1997) Effects of solar ultraviolet radiation at high altitude on the physiology and the biochemistry of a terricolous lichen (*Cetraria islandica* [L.] Ach.). *Symbiosis* 23: 23-197.
- Baker, A. C. (2003) Flexibility and specificity in coral-algal symbiosis: Diversity, ecology and biogeography of *Symbiodinium*. *Annu Rev Ecol Syst* 34: 34-661.
- Banaszak, A. T. , Iglesias-Prieto, R. , and Trench, R. K. (1993) *Scrippsiella velellae* sp. nov. (Peridinales) and *Gloeodinium viscum* sp. nov. (Phytodiniales), dinoflagellate symbionts of two hydrozoans (Cnidaria). *J Phycol* 29: 29-517.
- Basilier, K. , Granhall, U. , and Stenström, T.-A. (1978) Nitrogen fixation in wet minerotrophic moss communities of a subarctic mire. *Oikos* 31: 31-236.
- Batham, E. J. (1943) Vascular anatomy of New Zealand species of *Gunnera*. *Trans R Soc New Zealand* 73: 73-209.
- Baulina, O. I. , and Lobakova, E. S. (2003) A typical cell forms overproducing extracellular substances in populations of cycad cyanobionts. *J Microbiol* 72: 72-701.
- Beck, A. , Friedl, T. , and Rambold, G. (1998) Selectivity of photobiont choice in a defined lichen community: Inferences from cultural and molecular studies. *New Phytol* 139: 139-709.
- Beck, A. , Kasalicky, T. , and Rambold, G. (2002) Myco-photobiontal selection in a Mediterranean cryptogam community with *Fulgensia fulgida*. *New Phytol* 153: 153-317.
- Becker, V. E. (1980) Nitrogen fixing lichens in forests of the Southern Appalachian Mountains of North Carolina. *Bryologist* 83: 83-129.
- Becker, V. E. , Reeder, J. E. , and Stetler, R. (1977) Biomass and habitat of nitrogen-fixing lichens in an oak forest in the North Carolina Piedmont. *Bryologist* 80: 80-93.
- Becking, J. H. (1987) Endophyte transmission and activity in the *Anabaena-Azolla* association. *Plant Soil* 100: 100-183.
- Beer, S. , and Ilan, M. (1998) In situ measurements of photosynthetic irradiance responses of two Red Sea sponges growing under dim light conditions. *Mar Biol* 131: 131-613.
- Belfort, M. , Reaban, M. E. , Coetzee, T. , and Dalgaard, J. Z. (1995) Prokaryotic introns and inteins: A panoply of form and function. *J Bacteriol* 177: 177-3897.

Bergman, B. , Johansson, C. , and Söderback, E. (1992a) The Nostoc-Gunnera symbiosis. *New Phytol* 122: 122-379.

Bergman, B. , Johansson, C. , and Söderback, E. (1992b) Cyanobacterial-Plant symbioses. *Symbiosis* 14: 14-61.

Berryman, S. , and McCune, B. (2006) Epiphytic lichens along gradients in topography and stand structure in western Oregon, USA. *Pacific Northwest Fungi* 1: 1-1.

Bewley, C. A. , Holland, N. D. , and Faulkner, D. J. (1996) Two classes of metabolites from *Theonella swinhoei* are localized in distinct populations of bacterial symbionts. *Experientia* 52: 52-716.

Black, K. , and Osborne, B. (2004) An assessment of photosynthetic downregulation in cyanobacteria from *Gunnera-Nostoc* symbiosis. *New Phytol* 162: 162-225.

Black, K. G. , Parsons, R. , and Osborne, B. A. (2002) Uptake and metabolism of glucose in the *Nostoc-Gunnera* symbiosis. *New Phytol* 153: 153-297.

Bonnett, H. T. , and Silvester, W. B. (1981) Specificity in the *Gunnera-Nostoc* endosymbiosis. *New Phytol* 89: 89-121.

Brehm, U. , Krumbein, W. E. , and Palinska, K. A. (2003) Microbial spheres: A novel cyanobacterial-diatom symbiosis. *Naturwissenschaften* 90: 90-136.

Brenner, E. D. , Stevenson, D. W. , and Twigg, R. W. (2003) Cycads: evolutionary innovations and the role of plant-derived toxins. *Trends Plant Sci* 8: 8-1360.

Brewin, N. J. (2004) Plant cell wall remodeling in the *Rhizobium-legume* symbiosis. *Critical Rev Plant Sci* 23: 23-293.

Brodo, I. M. , and Richardson, D. H. S. (1979) Chimeroid associations in the genus *Peltigera*. *Lichenologist* 10: 10-157.

Brusca, R. C. , and Brusca, G. J. (1990) Phylum Porifera: The sponges. In: Sinauer, A. D. (Ed.) *Invertebrates*, Sinauer Press, Sunderland, Mass, USA pp. 181-210.

Bubrick, P. , and Galun, M. (1980) Proteins from the lichen *Xanthoria parietina* which bind to phycobiont cell walls. Correlation between binding patterns and cell wall chemistry. *Protoplasma* 104: 104-167.

Bubrick, P. , Frensdorff, A. , and Galun, M. (1985) Proteins from the lichen *Xanthoria parietina* which bind to phycobiont cell wall. Isolation and partial purification of an algal-binding protein. *Symbiosis* 1: 1-85.

Bubrick P. , Galun, M. , and Frensdorff, A. (1981) Proteins from the lichen *Xanthoria parietina* which bind to phycobiont cell wall. Localization in the intact lichen and cultured mycobiont.. *Protoplasma* 105: 105-207.

Buck, K. , and Bentham, W. N. (1998) A novel symbiosis between a cyanobacterium, *Synechococcus* sp., an aplastidic protist, *Solenicola setigera*, and a diatom, *Leptocylindrus mediterraneus*, in the open ocean. *Mar Biol* 132: 132-349.

Bödel, B. (1992) Taxonomy of lichenized procaryotic blue-green algae. In: Reisser, W. (Ed.) *Algae and Symbioses*. Biopress, Bristol, UK. pp. 301-324.

Bödel, B. (1999) Ecology and diversity of rock-inhabiting cyanobacteria in tropical regions. *Eur J Phycol* 34: 34-361.

Bödel, B. , and Henssen, A. (1983) *Chroococcidiopsis* (Cyanophyceae), a phycobiont in the lichen family Lichinaceae. *Phycologia* 22: 22-367.

Calvert, H. E. , Perkins, S. K. , and Peters, G. A. (1983) Sporocarp structure in the heterosporous water fern *Azolla mexicana* Presl. *Scanning Electron Microscopy* 3: 3-1499.

Calvert, H. E. , Pence, M. K. , and Peters, G. A. (1985) Ultrastructural ontogeny of leaf cavity trichomes in *Azolla* implies a functional role in metabolite exchange. *Protoplasma* 129: 129-210.

Calvert, H. E. , Perkins, S. K. , and Peters, G. A. (1985) Involvement of epidermal trichomes in the continuity of the *Azolla-Anabaena* symbiosis through the *Azolla* life cycle. *Am J Bot* 72: 808 (Abstr.).

Cameron, R. P. , and Richardson, D. H. S. (2006) Occurrence and abundance of epiphytic cyanolichens in protected areas of Nova Scotia, Canada. *Opuscula Philolichemnum* 3: 3-5.

Campbell, D. H. (1893) On the development of *Azolla filiculoides* Lam. *Ann Bot* 7: 7-155.

Campbell, E. L. , and Meeks, J. C. (1989) Characteristics of hormogonia formation by symbiotic *Nostoc* spp. in response to the presence of *Anthoceros punctatus* or its extracellular products. *Appl Environ Microbiol* 55: 55-125.

Campbell, E. L. , and Meeks, J. C. (1992) Evidence for plant-mediated regulation of nitrogenase expression in the *Anthoceros-Nostoc* symbiotic association. *J Gen Microbiol* 138: 138-473.

Campbell, E. L. , Brahmsha, B. , and Meeks, J. C. (1998) Mutation of an alternative sigma factor in the cyanobacterium *Nostoc punctiforme* results in increased infection of its symbiotic plant partner, *Anthoceros punctatus*. *J Bacteriol* 180: 180-4938.

Campbell, E. L. , Wong, F. C. Y. , and Meeks, J. C. (2003) DNA binding properties of the HrmR protein of *Nostoc punctiforme* responsible for transcriptional regulation of genes involved in the differentiation of hormogonia. *Mol Microbiol* 47: 47-573.

Campbell, E. L. , Summers, M. L. , Christman, H. , Martin, M. E. , and Meeks, J. C. (2007) Global gene expression patterns of *Nostoc punctiforme* in steady-state dinitrogen-grown heterocyst-containing cultures and at single time points during the differentiation of akinetes and hormogonia. *J Bacteriol* 189: 189-5247.

Campbell, J. , and Fredeen, A. L. (2004) *Lobaria pulmonaria* abundance as an indicator of macrolichen diversity in Interior Cedar-Hemlock forests of east-central British Columbia. *Can J Bot* 82: 82-970.

Capone, D. G. (2001) Marine nitrogen fixation: What's the fuss? *Commentary. Curr Opin Microbiol* 4: 4-341.

Carpenter, C. E. , Mueller, R. J. , Kazmierczak, P. , Zhang, L. , Villalon, D. K. , and Van Alfen, N. K. (1992) Effect of a virus on accumulation of a tissue-specific cell surface protein of the fungus *Cryphonectria* (*Endothia*) *parasitica*. *Mol Plant-Microbe Interact* 4: 4-55.

Carpenter, E. J. (2002) Marine cyanobacterial symbiosis. *Proc R Irish Acad* 102B: 15-18.

Carpenter, E. J. , and Janson, S. (2000) Intracellular cyanobacterial symbionts in the marine diatom *Climacodium frauenfeldianum* Grunow. *J Phycol* 36: 36-540.

Carpenter, E. J. , Montoya, J. P. , Burns, J. , Mulholland, M. , Subramaniam, A. , and Capone, D. G. (1999) Extensive bloom of a N₂ fixing symbiotic association in the tropical Atlantic Ocean. *Mar Ecol Prog Ser* 188: 188-273.

Casselmann, K. L. , and Hill, M. J. (1995) Lichens as a monitoring tool: A Pictou County (Nova Scotia) perspective. In: Herman, T. B. , Bondrup-Nielson, S. , Willison, J. H. M. , and Munro, N. W. P. (Eds.) *Ecosystem Monitoring in and Protected Areas. Proc II Internl Conf Science and the Management of Protected Areas*. Dalhousie University, Halifax, Nova Scotia, Canada. pp. 237-244.

Chapman, K. E. , Duggan, P. S. , Billington, N. A. , and Adams, D. G. (2008) Mutation of different sites in the *Nostoc punctiforme* *cyaC* gene, encoding the multidomain enzyme adenylyl cyclase, results in different levels of infection of the host plant *Blasia pusilla*. *J Bacteriol* 190: 190-1843.

Chaudhuri, H. , and Akhtar, A. R. (1931) The coral-like roots of *Cycas revoluta*, *Cycas circinalis* and *Zamia floridana* and the alga inhabiting them. *J Indian Bot Soc* 10: 10-43.

Cheshire, A. C. , Wilkinson, C. R. , Seddon, S. , and Wetsphalen, G. (1997) Bathymetric and seasonal changes in photosynthesis and respiration of the phototrophic sponge *Phyllospongia lamellosa* in comparison with respiration by the heterotrophic sponge *Ianthella basta* on Davies Reef, Great Barrier Reef. *Mar Freshwater Res* 48: 48-589.

Chiu, W.-L. , Peters, G. A. , Levieille, G. , Still, P. C. , Cousins, S. , Osborne, B. , and Elhai, J. (2005) Nitrogen deprivation stimulates symbiotic gland development in *Gunnera manicata*. *Plant Physiol* 139: 139-224.

Clarke, A. K. , Soitamo, A. , Gustafsson, P. , and Oquist, G. (1993) Rapid interchange between two distinct forms of cyanobacterial photosystem II reaction center protein D1 in response to photoinhibition. *Proc Natl Acad Sci USA* 90: 90-9973.

Cohen, M. F. , and Meeks, J. C. (1997) A hormogonium regulating locus, *hrmUA*, of the cyanobacterium *Nostoc punctiforme* strain ATCC 29133 and its response to an extract of a symbiotic plant partner *Anthoceros punctatus*. *Mol Plant-Microbe Interact* 10: 10-280.

Cohen, M. F. , and Yamasaki, H. (2000) Flavonoid-induced expression of a symbiosis-related gene in the cyanobacterium *Nostoc punctiforme*. *J Bacteriol* 182: 182-4644.

Cohen, M. F. , Sakihama, Y. , Takagi, Y. C. , Ichiba, T. , and Yamasaki, H. (2002) Synergistic effect of deoxyanthocyanins from symbiotic fern *Azolla* spp. on *hrmA* gene induction in the cyanobacterium *Nostoc punctiforme*. *Mol Plant-Microbe Interact* 15: 15-875.

Cohen, M. F. , Wallis, J. G. , Campbell, E. L. , and Meeks, J. C. (1994) Transposon mutagenesis of *Nostoc* sp. strain 29133, a filamentous cyanobacterium with multiple cellular differentiation alternatives. *Microbiology* 140: 140-3233.

Costa, J.-L. , Lindblad, P. , and Martinez Romero, E. (2004) Sequence based data supports a single *Nostoc* strain in individual coralloid roots of cycads. *FEMS Microbiol Ecol* 49: 49-481.

Costa, J.-L. , Paulsrud, P. , and Lindblad, P. (2002) The cyanobacterial tRNA^{Leu}(UAA) intron: Evolutionary patterns in a genetic marker. *Mol Biol Evol* 19: 19-850.

Costa, J.-L. , Paulsrud, P. , Rikinen, J. , and Lindblad, P. (2001) Genetic diversity of *Nostoc* symbionts endophytically associated with two bryophyte species. *Appl Environ Microbiol* 67: 67-4393.

Cren, M. , and Hirel, B. (1999) Glutamine synthetase in higher plants: Regulation of gene and protein expression from the organ to the cell. *Plant Cell Physiol* 40: 40-1187.

Czeika, H. , Czeika, G. , Guttová, A. , Farkas, E. , Lőkös, L. , and Halda, J. (2004) Phytogeographic and taxonomic remarks on eleven species of cyanophilic lichens from central Europe. *Preslia* 76: 76-183.

de Bary, A. (1879) *Die Erscheinung der Symbiose*. Strasburg, Germany.

DeLuca, T. H. , Zackrisson, O. , Nilsson, M. C. , and Sellstedt, A. (2002) Quantifying nitrogen-fixation in feather moss carpets of boreal forests. *Nature (London)* 419: 419-917.

Delwiche, C. F. , and Palmer, J. D. (1997) The origin of plastids and their spread via secondary symbiosis. *Plant Syst Evol Suppl* 11: 11-53.

Demming-Adams, B. (1990) Carotenoids and photoprotection in plants: a role for the xanthophyll zeaxanthin. *Biochim Biophys Acta* 1020: 1020-1121.

Denison, R. , Caldwell, B. , Bormann, B. , Eldred, L. , Swanberg, C. , and Anderson, S. (1977) The effects of acid rain on nitrogen fixation in western Washington coniferous forests. *Water Air and Soil Pollution* 8: 8-21.

DePriest, P. T. , and Been, M. D. (1992) Numerous group I introns with variable distributions in the ribosomal DNA of a lichen fungus. *J Mol Biol* 228: 228-315.

de Vocht, M. L. , Reviakine, I. , Wösten, H. A. B. , Brisson, A. D. R. , Wessels, J. G. H. , and Robillard, G. T. (2000) Structural and functional role of the disulfide bridges in the hydrophobin SC3. *J Biol Chem* 275: 275-28428.

de Vries, O. M. H. , Fekkes, M. P. , Wösten, H. A. B. , and Wessels, J. G. H. (1993) Insoluble hydrophobin complexes in the walls of Schizophyllum commune and other filamentous fungi. *Arch Microbiol* 159: 159-330.

Díaz, E.-M. , Sacristán, M. , Legaz, M.-E. , and Vicente, C. (2009) Isolation and characterization of a cyanobacterium-binding protein and its cell wall receptor in the lichen *Peltigera canina*. *Plant Signal Behav* 4: 4-598.

Díaz, E.-M. , Vicente-Manzanares, M. , Sacristán, M. , Vicente, C. , and Legaz, M.-E. (2011) Fungal lectin of *Peltigera canina* induces chemotropism of compatible *Nostoc* cells by constriction-relaxation pulses of cyanobiont cytoskeleton. *Plant Signal Behav* 6: 6-1525.

Dick, H. , and Stewart, W. D. P. (1980) The occurrence of fimbriae on a N₂-fixing cyanobacterium which occurs in lichen symbioses. *Arch Microbiol* 124: 124-207.

Dore, J. E. , Letelier, R. M. , Church, M. J. , and Karl, D. M. (2008) Summer phytoplankton blooms in the oligotrophic North Pacific subtropical gyre: Historical perspective and recent observations. *Prog Oceanogr* 76: 2-38. doi:10.1016/j.pcean.2007.10.002

Drum, R. W. , and Pankratz, S. (1965) Fine structure of an unusual cytoplasmic inclusion in the diatom genus *Rhopalodia*. *Protoplasma* 60: 60-141.

Duckett, J. G. , and Renzaglia, K. S. (1993) The reproductive biology of the liverwort *Blasia pusilla* L. *J Bryol* 17: 17-541.

Duckett, J. G. , Prasad, A. K. S. K. , Davies, D. A. , and Walker, S. (1977) A cytological analysis of the *Nostoc*-bryophyte relationship. *New Phytol* 79: 79-349.

Duckett, J. G. , Toth, R. , and Soni, S. L. (1975) An ultrastructural study of the *Azolla*, *Anabaena azollae* relationship. *New Phytol* 75: 75-111.

Duff, R. J. , Cargill, D. C. , Villarreal, J. C. , and Renzaglia, K. S. (2004) Phylogenetic relationships of the hornworts based on *rbcL* sequence data: Novel relationships and new insights. In: Goffinet, B. , Hollowell, V. , and Magill, R. (Eds.) *Molecular Systematics of Bryophytes*. Monographs in Systematic Botany from the Missouri Botanical Garden 98: 98-141.

Duggan, P. S. , Gottardello, P. , and Adams, D. G. (2007) Molecular analysis of genes in *Nostoc punctiforme* involved in pilus biogenesis and plant infection. *J Bacteriol* 189: 189-4547.

Duglas, A. E. (1994) *Symbiotic Interactions*. Oxford University Press, Oxford, UK. pp. 148.

Dujon B. (1989) Group I introns as mobile genetic elements: Facts and mechanistic speculations. A review. *Gene* 82: 82-91.

Dunham, D. G. , and Fowler, K. (1987) Megaspore germination, embryo development and maintenance of the symbiotic association in *Azolla filiculoides* Lam. *Bot J Linnean Soc* 95: 95-143.

Dyer, P. S. (2002) Hydrophobins in the lichen symbiosis. *New Phytol* 154: 154-210.

Edwards, T. C., Jr. , Cutler, R. , Geiser, L. , Alegria, J. , and McKenzie, D. (2004) Assessing rarity and seral stage association of species with low detectability: Lichens in western Oregon and Washington forests. *Ecol Applications* 14: 14-414.

Egger, K. N. (1995) Molecular analysis of ectomycorrhizal fungal communities. *Can J Bot* 73 (Suppl): S1415-S1422.

Ekman, M. , Tollback, P. , Klintt, J. , and Bergman, B. (2006) Protein expression profiles in an endosymbiotic cyanobacterium revealed by a proteomic approach. *Mol Plant-Microbe Interact* 19: 19-1251.

Elifio, S. L. , Da Silva, M. , De Laourdes, C. C. , Iacomini, M. , and Gorin, P. A. J. (2000) A lectin from lichenized basidiomycete *Dictyonema glabratum*. *New Phytol* 148: 148-327.

Ellyson, W. J. , and Sillett, S. C. (2003) Epiphyte communities on Sitka Spruce in an old-growth redwood forest. *Bryologist* 106: 106-197.

Enderlin, C. S. , and Meeks, J. C. (1983) Pure culture and reconstitution of the *Anabaena-Azolla* symbiotic association. *Planta* 158: 158-257.

Engel, S. , and Pawlik, J. R. (2000) Allelopathic activities of sponge extracts. *Mar Ecol Prog Ser* 207: 207-273.

Farmer, A.M. , Bates, J. F. , and Bell, J. N. B. (1992) Ecophysiological effects of acid rain on bryophytes and lichens. In: Bates, J. W. , and Farmer, A. M. (Eds.) *Bryophytes and Lichens in a Changing Environment*, Chapter 11. Oxford University Press, Oxford, UK. pp. 284-313.

Faulkner, D. J. , Unson, M. D. , and Bewley, C. A. (1994) The chemistry of some sponges and their symbionts. *Pure Appl Chem* 66: 66-1883.

Feldman, J. (1933) Sur quelques cyanophycées vivant dans le tissu des éponges de banyules. *Arch Zool Exp Gén* 75: 331-404.

Feoktistov, A. S. , Kitashov, A. V. , and Lobakova, E. S. (2009) The characterization of lectins from the tripartite lichen *Peltigera aphthosa* (L.) Willd. *Moscow Univ Biol Sci Bull* 64: 64-123.

Fiedler, G. , Muro-Pastor, A. , Flores, E. , and Maldener, I. (2001) Ntc-dependent expression of the devBCA operon, encoding a heterocyst-specific ATP-binding cassette transporter in *Anabaena* spp. *J Bacteriol* 183: 183-3795.

Fisher, R. , and Long, S. R. (1992) Rhizobium-plant signal exchange. *Nature (London)* 357: 357-655.

Floener, L. , and Bothe, H. (1980) Nitrogen fixation in *Rhopalodia gibba*, a diatom containing blue-green inclusions symbiotically. In: Schwemmler, W. , and Schenk, H. E. A. (Eds.) *Endocytobiology, Endosymbiosis and Cell Biology*. Walter de Gruyter & Co., Berlin, Germany. pp. 541-552.

Flowers, A. E. , Garson, M. J. , Webb, R. I. , Dumdei, E. J. , and Charan, R. D. (1998) Cellular origin of chlorinated diketopiperazines in the dictyoceratid sponge *Dysidea herbacea* (Keller). *Cell Tissue Res* 292: 292-597.

Fong, A. A. , Karl, D. , Lukas, R. , Letelier, R. M. , Zehr, J. P. , Church, M. J. (2008) Nitrogen fixation in an anticyclonic eddy in the oligotrophic North Pacific Ocean. *Isme J* 2: 2-663.

Forman, R. T. T. (1975) Canopy lichens with blue-green algae: A nitrogen source in a Columbian rain forest. *Ecology* 56: 56-1176.

Foster, R. A. , and Zehr, J. P. (2006) Characterization of diatom-cyanobacteria symbioses on the basis of nifH, hetR, and 16S rRNA sequences. *Environ Microbiol* 8: 8-1913.

Foster, R. A. , Kuypers, M. M. M. , Vagner, T. , Paerl, R. W. , Musat, N. , and Zehr, J. P. (2011) Nitrogen fixation and transfer in the open ocean diatom cyanobacterial symbioses. *Isme J* 5: 1484-1493. doi:10.1038/ismej.204.26

Foster, R. A. , Subramaniam, A. , and Zehr, J. P. (2009) Distribution and activity of diazotrophs in the Eastern Equatorial Atlantic. *Environ Microbiol* 11: 11-741.

Foster, R. A. , Subramaniam, A. , Mahaffey, C. , Carpenter, E. J. , Capone, D. G. , and Zehr, J. P. (2007) Influence of the Amazon River plume on distributions of free-living and symbiotic cyanobacteria in the western tropical north Atlantic Ocean. *Limnol Oceanogr* 52: 52-517.

Fox, G. E. , Wisotzkey, J. D. , and Jurtshuk, P. Jr. (1992) How close is close: 16S rRNA sequence identity may not be sufficient to guarantee species identity. *Int J Syst Bacteriol* 42: 42-166.

Franche, C. , and Cohen-Bazire, G. (1985) The structural nif genes of four symbiotic *Anabaena azollae* show a highly conserved physical arrangement. *Plant Sci* 39: 39-125.

Franché, C. , and Cohen-Bazire, G. (1987) Evolutionary divergence in the nif K, D, H genes region among nine symbiotic *Anabaena azollae* and between *Anabaena azollae* and some free-living heterocystous cyanobacteria. *Symbiosis* 3: 3-159.

Frank, A. B. (1877) Ueber die biologischen Verhältnisse des Thallus einiger Krustenflechten. *Beitr Biol Pflanzen* 2: 2-123.

Friedl, T. , and Büdel, B. (1996) Photobionts. In: Nash, T.H. III , (Ed.) *Lichen Biology*. Cambridge University Press, Cambridge, UK. pp. 217-239.

Frost, T. M. , and Williamson, C. E. (1980) In situ determination of the effect of symbiotic algae on the growth of freshwater sponge *Spongilla lacustris*. *Ecology* 61: 61-1361.

Frugier, F. , Kosuta, S. , Murray, J. , Crespi, M. , and Szczyglowski, K. (2008) Cytokinin: A secret agent of symbiosis. *Trends Plant Sci* 13: 13-115.

Gaino, E. , Sciscioli, M. , Lepore, E. , Rebora, M. , and Corriero, G. (2006) Association of the sponge *Tethya orphei* (Porifera, Desmospongiae) with filamentous cyanobacteria. *Invertebrate Biol* 125: 125-281.

Galloway, D. J. (1988) Nomenclatural notes on *Pseudocyphellaria* VI. Two endemic Australian taxa. *Lichenologist* 29: 29-599.

Galun, M. , and Bubrik, P. (1984) Physiological interactions between the partners of the lichen symbiosis. In: Linskens, H. F. , and Heslop-Harrison, J. (Eds.) *Encyclopedia of Plant Physiology: Cellular Interactions*. Springer, Berlin, Germany. pp. 362-401.

Garcia-Pichel, F. , and Castenholz, R. W. (1993) Occurrence of UV-absorbing, mycosporine-like compounds among cyanobacterial isolates and an estimate of their screening capacity. *Appl Environ Microbiol* 59: 59-163.

Garson, M. J. (2001) Ecological perspectives on marine natural product biosynthesis. In: McClintock, J. B. , and Baker, B. J. (Eds.) *Marine Chemical Ecology*. CRC Press, Boca Raton, Florida, FL, USA. pp. 71-114.

Gates, J. E. , Fisher, R. W. , Goggin, T. W. , and Azrolan, N. I. (1980) Antigenic differences between *Anabaena azollae* fresh from the *Azolla* fern leaf cavity and the free-living cyanobacteria. *Arch Microbiol* 128: 128-226.

Gauslaa, Y. (1995) Lobarion, an epiphytic community of ancient forests, threatened by acid rain. *Lichenologist* 27: 27-59.

Gauslaa, Y. , and Solhaug, K. A. (1996) Differences in the susceptibility to light stress between epiphytic lichens of ancient and young boreal forest stands. *Functional Ecology (British Ecological Society)* 10: 344-354. doi:10.2307/2390282

Gebhardt, J. S. , and Nierzwicki-Bauer, S. A. (1991) Identification of a common cyanobacterial symbiont associated with *Azolla* spp. through molecular and morphological characterization of free-living and symbiotic cyanobacteria. *Appl Environ Microbiol* 57: 57-2141.

Gehrig, H. , Schüßler, A. , and Kluge, M. (1996) *Geosiphon pyriformis*, a fungus forming endocytobiosis with *Nostoc* (cyanobacteria), is an ancestral member of the Glomales: Evidence by SSU rRNA analysis. *J Mol Evol* 43: 43-71.

Gehringer, M. M. , Pengelly, J. J. L. , Cuddy, W. S. , Fieker, C. , Forster, P. I. , and Neilan, B. A. (2010) Host selection of symbiotic cyanobacteria in 31 species of the Australian cycad genus: *Macrozamia* (Zamiaceae). *Mol Plant-Microbe Interact* 23: 811-822. doi: 10.1094/MPMI-23-6-0811

Geitler, L. (1977) Zur Entwicklungsgeschichte der Epithemiaceen *Epithemia*, *Rhopalodia* and *Denticula* (Diatomophyceae) und ihre vermutlich symbiotischen Sphäroidkörper. *Plant Syst Evol* 128: 128-265.

Gentili, F. , Nilsson, M.-C. , Zackrisson, O. , DeLuca, T. H. , and Sellstedt, A. (2005) Physiological and molecular diversity of feather moss associative N₂-fixing cyanobacteria. *J Exp Bot* 56: 56-3121.

- Godoy, R. , Oyarún, C. E. , and Gerding, V. (2001) Precipitation chemistry in deciduous and evergreen *Nothofagus* forests of southern Chile under low-deposition climate. *Basic Appl Ecol* 2: 2-65.
- Goffinet, B. , and Bayer, R. J. (1997) Characterization of mycobionts of photomorph pairs in the *Peltigerineae* (lichenized ascomycetes) based on internal transcribed spacer sequences of the nuclear ribosomal DNA. *Fungal Genet Biol* 21: 21-228.
- Goffinet, B. , and Hastings, R. I. (1995) Two new sorediate taxa of *Peltigera*. *Lichenologist* 27: 27-43.
- Gómez, R. , Erpenbeck, D. , van Dijk, T. , Richelle-Maurer, E. , Devijver, C. , Brackman, J. C. , Woldringh, C. , and van Soest, R. W. M. (2002) Identity of cyanobacterial symbiont of *Xestospongia muta*. *Boll Mus Ist Biol Univ Genova* 66-67: 82-83.
- Gómez, F. , Furuya, K. , and Takeda, S. (2005) Distribution of the cyanobacterium *Richelia intracellularis* as an epiphyte of the diatom *Chaetoceros compressus* in the western Pacific Ocean. *J Plankton Res* 27: 27-323.
- Goward, T. (1994) Notes on old growth dependent epiphytic macrolichens in inland British Columbia, Canada. *Acta Bot Fennica* 150: 150-231.
- Goward, T. , and Arsenault, A. (2000a) Inland old-growth rain forests: Safe havens for rare lichens? In: Darling, L. M. (Ed.) *Proc Biology and Management of Species and Habitats at Risk*, 2: 759-766. Ministry of Environment, Lands and Parks, Victoria, B. C. and University College of the Cariboo, Kamloops, B. C.
- Goward, T. , and Arsenault, A. (2000b) Cyanolichen distribution in young unmanaged forests: A dripzone effect? *Bryologist* 103: 103-128.
- Goward, T. , Goffinet, B. , and Vitikainen, O. (1995) Synopsis of the genus *Peltigera* (lichenized Ascomycetes) in British Columbia, with a key to the North American species. *Can J Bot* 73: 73-91.
- Granhall, U. , and Hofsten, A. (1976) Nitrogenase activity in relation to intracellular organisms in *Sphagnum* mosses. *Physiol Plant* 36: 36-88.
- Grilli, M. (1963) Osservazioni sulle strutture e le infrastrutture delle cellule dei tubercoli radicali di *Cycas revoluta*. *Annali della Facoltà di Agraria* 3: 3-467.
- Grilli-Caiola, M. (1974) A light and electron microscope study of the blue-green algae living either in the coralloid roots of *Macrozamia communis* or isolated in culture. *Giornale Botanica Italiano* 108: 108-161.
- Grilli-Caiola, M. (1975a) A light and electron microscope study of the blue-green algae living in the coralloid roots of *Encephalartos altensteinii* and in culture. *Phycologia* 14: 14-25.
- Grilli-Caiola, M. (1975b) Structural and ultrastructural aspects of blue-green algae growing in the coralloid roots of *Dioon edule* and in culture. *Phykos* 14: 14-29.
- Grilli-Caiola, M. (1980) On the phycobionts of cycad coralloid roots. *New Phytol* 85: 85-537.
- Grilli-Caiola, M. , Forni, C. , and Castagnola, M. (1992) *Anabaena azollae* akinetes in the sporocarps of *Azolla filiculoides* Lam. *Symbiosis* 14: 14-247.
- Grobbelaar, N. , Scott, W. E. , Hattingh, W. , and Marshall, J. (1987) The identification of the coralloid endophytes of the southern African cycads and the ability of the isolates to fix dinitrogen. *S Afr J Bot* 53: 53-111.
- Guevara, R. , Armesto, J. J. , and Caru, M. (2002) Genetic diversity of *Nostoc* microsymbionts from *Gunnera tinctoria* revealed by PCR-STR fingerprinting. *Microb Ecol* 44: 44-127.
- Hall, J. W. , and Swanson N. P. (1968) Studies on fossil *Azolla*: *Azolla montana*, a Cretaceous megaspore with many small floats. *Am J Bot* 55: 55-1055.
- Hallbauer, D. K. , Jahns, H. M. , and Beltmann, H. A. (1977) Morphological and anatomical observations on some Precambrian plants from the Witwaterstand, South Africa. *Geol Rundschau* 66: 66-477.
- Harder, R. (1917) Ernährungsphysiologische Untersuchungen an Cyanophyceen, hauptsächlich dem endophytischen *Nostoc punctiforme*. *Zeitschrift für Botanik* 9: 9-143.
- Hedenås, H. , and Ericson, L. (2003) Response of epiphytic lichens on *Populus tremula* in a selective cutting experiment. *Ecological Applications* 13: 13-1124.
- Heinbokel, J. F. (1986) Occurrence of *Richelia intracellularis* (Cyanophyta) within diatoms *Hemiaulus hauckii* and *H. membranaceus* off Hawaii. *J Phycol* 22: 22-399.
- Hentschel, U. , Hopke, J. , Horn, M. , Friedrich, A. B. , Wagner, M. , Hackr, J. , and Moore, B. S. (2002) Molecular evidence for a uniform microbial community in sponges from different oceans. *Appl Environ Microbiol* 68: 68-4431.
- Hentschel, U. , Schmid, M. , Wagner, M. , Fieseler, L. , Gernert, C. , and Hacker, J. (2001) Isolation and phylogenetic analysis of bacteria with antimicrobial activities from the Mediterranean sponges, *Aplysina aerophoba* and *Aplysina cavernicola*. *FEMS Microbiol Ecol* 35: 35-305.
- Herrera-Campos, M. A. , Huhndorf, S. , and Löcking, R. (2005) The foliicolous lichen flora of Mexico IV: A new, foliicolous species of *Pyrenothrix* (Chaetothyriales: Pyrenotrichaceae). *Mycologia* 97: 97-356.
- Herrero, A. , Muro-Pastor, A. M. , and Flores, E. (2001) Nitrogen control in cyanobacteria. *J Bacteriol* 183: 183-411.
- Hill, D. J. (1975) The pattern of development of *Anabaena* in the *Azolla*-*Anabaena* symbiosis. *Planta* 122: 122-179.
- Hill, D. J. (1977) The role of *Anabaena* in the *Azolla*-*Anabaena* symbiosis. *New Phytol* 78: 78-611.
- Hill, D. J. (1994) The nature of symbiotic relationship in lichens. *Endeavour* 18: 18-96.
- Hillis, D. M. , and Dixon, M. T. (1991) Ribosomal DNA: Molecular evolution and phylogenetic inference. *Quart Rev Biol* 66: 66-411.
- Hill, M. S. (1996) Symbiotic zooxanthellae enhance boring and growth rates of the tropical sponge. *Anthosigmella varians* forma *variens*. *Mar Biol* 125: 125-649.
- Hinde, R. , Pironit, F. , and Borowitzka, M. A. (1994) Isolation of *Oscillatoria spongeliae*, the filamentous cyanobacterial symbiont of the marine sponge *Dysidea herbacea*. *Mar Biol* 119: 119-199.
- Hinrichsen, D. (1997) Coral reefs in crisis. *BioScience* 47: 47-554.
- Hirose, E. , Maruyama, T. , Cheng, L. , and Lewin, R. A. (1996) Intracellular symbiosis of a photosynthetic prokaryote *Prochloron* sp., in a colonial ascidian. *Invertebrate Biol* 115: 115-343.
- Hirsch, A. M. (2004) Plant microbe symbioses: A continuum from commensalisms to parasitism. *Symbiosis* 37:
- Holder, J. M. , Wynn-Williams, D. D. , Rull Perez, F. , and Edwards, H. G.M. , (2000) Raman spectroscopy of pigments and oxalates in situ within epilithic lichens: *Acarospora* from the Antarctic and Mediterranean. *New Phytol* 145: 145-271.
- Holtan-Hartwig, J. (1993) The lichen genus *Peltigera* exclusive of the *P. canina* group, in Norway. *Sommerfeltia* 15: 15-21.
- Honegger, R. (1991) Functional aspects of the lichen symbiosis. *Annu Rev Plant Physiol Plant Mol Biol* 42: 42-553.

Honegger, R. (1993) Developmental biology of lichens. *New Phytol* 125: 125-659.

Honegger, R. (2000) Great Discoveries in Bryology and Lichenology: Simon Schwendener (1829-1919) and the dual hypothesis of lichens. *Bryologist* 103: 103-307.

Honegger, R. , and Hatsch, A. (2001) Immunocytochemical location of the (1 → 3) (1 → 4)-β-glucan lichenin in the lichen-forming ascomycete *Cetraria islandica* (Icelandic moss). *New Phytol* 150: 150-739.

Honegger, R. , Peter, M. , and Scherrer, S. (1996) Drought-induced structural alterations at the mycobiont-photobiont interface in a range of foliose macrolichens. *J Protoplasma* 190: 190-221.

Huss-Danell, K. (1977) Nitrogenase activity in the lichen *Stereocaulon paschele*: Recovery after dry storage. *Physiol Plant* 41: 41-158.

Hyvärinen, M. , Hårdling, R. , and Tuomi, J. (2002) Cyanobacterial lichen symbiosis: the fungal partner as an optimal harvester. *Oikos* 98: 98-498.

Ingram, G. A. (1982) Haemagglutinins and haemolysins in selected lichen species. *Bryologist* 85: 85-389.

Ireland, R. J. , and Lea, P. J. (1999) The enzymes of glutamine, glutamate, asparagine, and aspartate metabolism. In: Singh, B. K. (Ed.) *Plant Amino Acids, Biochemistry and Biotechnology*. Marcel Dekker, New York, NY, USA. pp. 49-109.

James, P. W. , Hawksworth, D. L. , and Rose, F. (1977) Lichen communities in the British Isles: A preliminary conspectus. In: Seaward, M. R. D. (Ed.) *Lichen Ecology*. Academic Press, London, England, UK. pp. 295-413.

Janson, S. , Rai, A. N. , and Bergman, B. (1995) Intracellular cyanobiont *Richelia intracellularis*. Ultrastructure and immunolocalization of phycoerythrin, nitrogenase, Rubisco and glutamine synthetase. *Mar Biol* 124: 124-211.

Janson, S. , Wouters, J. , Bergman, B. , and Carpenter, E. J. (1999) Host specificity in the *Richelia*-diatom symbiosis revealed by hetR gene sequence analysis. *Environ Microbiol* 1: 1-431.

Johansson, C. , and Bergman, B. (1992) Early events during the establishment of *Nostoc*-*Gunnera* symbiosis. *Planta* 188: 188-403.

Johansson, C. , and Bergman, B. (1994) Reconstitution of symbiosis of *Gunnera manicata* Linden: Cyanobacterial specificity. *New Phytol* 126: 126-643.

Joneson, S. , Armaleo, D. , and Lutzoni, F. (2011) Fungal and algal gene expression in early developmental stages of lichensymbiosis. *Mycologia* 103: 291-306. doi:10.3852/10-064

Jönsson, B. (1894) Studier öfver alparasitism hos *Gunnera* L. *Botaniska Notiser* 1-20.

Jordan, W. P. (1972) Erumpent cephalodia, an apparent case of phycobial influence on lichen morphology. *J Phycol* 8: 8-112.

Joseph, C. M. , and Meeks, J. C. (1987) Regulation of expression of glutamine synthetase in a symbiotic *Nostoc* strain associated with *Anthoceros punctatus*. *J Bacteriol* 169: 169-2471.

Jovan, S. (2002) A landscape-level analysis of epiphytic lichen diversity in northern and central California: Environmental predictors of species richness and potential observer effects. *Bull Calif Lichen Soc* 9: 9-10.

Jovan, S. , and McCune, B. (2004) Regional variation in epiphytic macrolichen communities in northern and central California forests. *Bryologist* 107: 107-328.

Kallio, P. (1974) Nitrogen fixation in subarctic lichens. *Oikos* 25: 25-194.

Kaplan, D. , and Peters, G. A. (1981) The *Azolla*-*Anabaena azollae* relationship. X. ¹⁵N₂ fixation and transport in main stem axes. *New Phytol* 89: 89-337.

Kardish, N. , Silberstein, L. , Flemminger, N. , and Galun, M. (1991) Lectin from the lichen *Nephroma laevigatum*. Localization and function. *Symbiosis* 11: 11-47.

Khamar, H. J. , Breathwaite, E. K. , Prasse, C. E. , Fraley, E. R. , Secor, C. R. , Chibane, F. L. , Elhai, J. , and Chiu, W.-L. (2010) Multiple role of soluble sugars in the establishment of *Gunnera*-*Nostoc* endosymbiosis. *Plant Physiol* 154: 154-1381.

Kimor, B. , Gordon, N. , and Neori, A. (1992) Symbiotic associations among the microplankton in oligotrophic marine environments, with special reference to Gulf of Aqaba, Red Sea. *J Plankton Res* 14: 14-1217.

Kimor, B. , Reid, F. M. , and Jordan, J. B. (1978) An unusual occurrence of *Hemiaulus membranaceus* Cleve (Bacillariophyceae) with *Richelia intracellularis* Schmidt (Cyanophyceae) off the coast of Southern California in October 1976. *Phycologia* 17: 17-162.

Kimura, J. , and Nakano, T. (1990) Reconstitution of *Blasia*-*Nostoc* symbiotic association under axenic conditions. *Nova Hedwigia* 50: 50-181.

Kirk, P. M. , Cannon, P. F. , David, J. C. , and Stalpers, J. A. (2001) *Ainsworth and Bisby's Dictionary of the Fungi*, 9th edn. CAB International, Egham, UK.

Kitajima, S. , Furuya, K. , Hashihama, F. , Takeda, S. , and Kanda, J. (2009) Latitudinal distribution of diazotrophs and their nitrogen fixation in the tropical and subtropical western North Pacific. *Limnol Oceanogr* 54: 537-547. doi:10.4319/10.2009.54.2.0537

Kjems, J. , and Garrett, R. A. (1991) Ribosomal RNA introns in archaea and evidence for RNA conformational changes associated with splicing. *Proc Natl Acad Sci USA* 88: 88-439.

Kluge, M. (2002) A fungus eats a cyanobacterium: The story of the *Geosiphon pyriformis* endocyanosis. *Proc R Irish Acad* 102B: 11-14.

Kneip, C. , Lockhart, P. , Voß, C. , and Maier, U. G. (2007) Nitrogen fixation in eukaryotes. New models for symbiosis. *Evol Biol* 7: 55. doi:10.1186/1471-2148/7/55

Knight, C. D. , and Adams, D. G. (1996) A method for studying chemotaxis in nitrogen fixing cyanobacterium-plant symbiosis. *Physiol Mol Plant Path* 49: 49-73.

Kobiler, D. , Cohen-Sharon, A. , and Tel-Or, E. (1981) Recognition between the N₂-fixing *Anabaena* and the water fern *Azolla*. *FEBS Lett* 133: 133-157.

Koike, I. , and Suzuki, T. (1996) Nutritional diversity of symbiotic ascidians in a Fijian seagrass meadow. *Ecol Res* 11: 11-381.

Koike, I. , Yamamuro, M. , and Pollard, P. C. (1993) Carbon and nitrogen budgets of two ascidians and their symbiont, *Prochloron*, in a tropical seagrass meadow. *Aus J Mar Freshwater Res* 44: 44-173.

Kühl, M. , and Larkum, A. W. D. (2002) The microenvironment and photosynthetic performance of *Prochloron* sp. in symbiosis with didemnid Ascidians. In: Seckbach, J. (Ed.) *Cellular Origin in Extreme Habitats*. Vol. 3. Symbiosis, Mechanisms and Model Systems. Kluwer Academic Publishers Dordrecht, The Netherlands. pp. 273-290.

Kuhse, M. G. , Strickland, R. , and Palmer, J. D. (1990) An ancient group I intron shared by eubacteria and chloroplasts. *Science* 250: 250-1570.

Kulkarni, V. V. , Chitari, R. R. , Narle, D. D. , Patil, J. S. , and Anil, A. C. (2010) Occurrence of cyanobacteria-diatom symbioses in the Bay of Bengal: Implications in biogeochemistry. *Curr Sci* 99: 99-736.

Ladha, J. K. , and Watanabe, I. (1982) Antigenic similarity among *Anabaena azollae* separated from different species of *Azolla*. *Biochem Biophys Res Comm* 109: 109-675.

Ladha, J. K. , and Watanabe, I. (1984) Antigenic analysis of *Anabaena azollae* and the role of lectin in the *Azolla*-*Anabaena* symbiosis. *New Phytol* 98: 98-295.

Lambowitz, A. M. (1989) Infectious introns. *Cell* 56: 56-323.

Lambowitz, A. M. , Caprara, M. G. , Zimmerly, S. , and Perlman, P. S. (1999) Group I and group II ribozymes as RNPs: Clues to the past and guides to the future. In: Gesteland, R. F. , Cech, T. R. , and Atkins, J. F. (Eds.) *The RNA World*. Cold Spring Harbor Laboratory Press, Cold Spring Harbor, New York, NY, USA. pp. 451-485.

Lancien, M. , Gadal, P. , and Hodges, M. (2000) Enzyme redundancy and the importance of 2-oxoglutarate in higher plant ammonium assimilation. *Plant Physiol* 123: 123-817.

Lange, O. L. , Kilian, E. , and Ziegler, H. (1986) Water vapor uptake and photosynthesis in lichens: performance differences in species with green and blue-green algae as phycobionts. *Oecologia* 71: 71-104.

Lange, O. L. , Green, T. G. A. , and Ziegler, H. (1988) Water related photosynthesis and carbon isotope discrimination in species of taxonomic distribution and existence of regions of homology with symbiotic genes of *Rhizobium*. *Can J Microbiol* 37: 37-171.

Larkum, A. W. D. (1999) The cyanobacteria of coral reefs. *Marine cyanobacteria*. In: Charpy, L. , and Larkum, A. W. D. (Eds.) *Bull de Institut Oceanographique Monaco Numero special 19*. Monaco Musee Oceanographique. pp. 149-167.

Larkum, A. W. D. , Cox, G. C. , and Dibrayawan, T. P. (1988) Prokaryotic algal symbionts of coral reef sponges. *Proc 6th Int Coral Reef Symp* 1983. 3: 3-163.

Larkum, A. W. D. , Cox, G. C. , Hiller, R. G. , Parry, D. L. , and Dibbayawan, T. P. (1987) Filamentous cyanophytes containing phycoerythrin and in symbiosis with sponges and an ascidian of coral reefs. *Marine Biol* 95: 95-111.

La Roche, J. , van der Staay, G. W. M. , Partensky, F. , Ducret, A. , Aebersold, R. , Li, R. , Golden, S. S. , Hiller, R. G. , Wrench, P. M. , Larkum, A. D. M. , and Green, B. R. (1996) Independent evolution of the Prochlorophyta and green plant chlorophyll a/b light-harvesting proteins. *Proc Natl Acad Sci USA* 93: 93-15244.

Laundon, J. R. (1995) On the classification of lichen photomorphs. *Taxon* 44: 44-387.

Lee, Y. K. , Lee, J.-H. , and Lee, H. K. (2001) Microbial symbiosis in marine sponges. *J Microbiol (Korea)* 39: 39-254.

Legaz, M. E. , Fontaniella, B. , Millanes, A. M. , and Vicente, C. (2004) Secreted arginases from phylogenetically far-related lichen act as cross-recognition factor for two different algal cells. *Eur J Cell Biol* 83: 83-91.

Lehr, H. , Fleminger, G. , and Galun, M. (1995) Lectin from the lichen *Peltigera membranacea* (Ach.) Nyl.: Characterization and function. *Symbiosis* 18: 18-21.

Lehr, H. , Galun, M. , Ott, S. , Jahns, H. M. , and Fleminger, G. (2000) *Cephalodia* of the lichen *Peltigera aphthosa*. Specific recognition of the compatible photobiont. *Symbiosis* 29: 29-357.

Lemmermann, E. (1899) *Ergebnisse einer Reise nach dem Pacific (H. Scauinsland 1896/97)*. *Planktanolgen, Abhandl Aus Naturw Ver Bremen* 16: 16-313.

Lemmermann, E. (1905) *Die Algenflora der Sandwich-Inseln. Ergebnisse einer nach dem Pacific, H. Schauinsland 1896/97*. *Engler's Bot Jahrbücher Syst, Pflanzengeschichte Pflanzengeographie* 34: 34-607.

Le Moal, M. , Collin, H. , and Biegala, I. C. (2011) Intriguing diversity among diazotrophic picoplankton along a Mediterranean transect: A dominance of rhizobia. *Biogeosci* 8: 827-840. doi:10.5194/bg-8-827-2011.

Lesser, M. P. , Mazel, C. H. , Gorbunov, M. Y. , and Falkowski, P. G. (2004) Discovery of symbiotic nitrogen-fixing cyanobacteria in corals. *Science* 305: 305-997.

Lewin, B. (2008) *Genes IX*. Jones and Bartlett Publishers, Boston and London.

Lewin, R. A. (1975) A marine *Synechocystis* (Cyanophyta, Chroococcales) epizoid on ascidians. *Phycologia* 14: 14-153.

Lewin, R. A. , and Cheng, L. (Eds.) (1989) *Prochloron—a microbial enigma*. Chapman & Hall, New York, NY, USA.

Lewin, R. A. , and Withers, N. W. (1975) Extraordinary pigment composition of a prokaryotic alga. *Nature (London)* 256: 256-735.

Lin, C. , and Watanabe, I. (1988) Study on the association between *Anabaena azollae* and *Azolla microphylla* during the germination of megasporocarps. *Symbiosis* 5: 5-199.

Lindblad, P. (1984) Diversion between C₂H₂-reduction and heterocyst frequency in a cycad root. In: Veeger, C. V. , and Newton, W. E. (Eds.) *Advances in Nitrogen Fixation Research*. Nühoff/Junk, Publishers, The Hague. The Netherlands. pp. 511.

Lindblad, P. , Atkins, P. , and Pate, J. S. (1991) N₂-fixation by freshly isolated *Nostoc* from coralloid roots of the cycad *Macrozamia riedlei* (Fisch-Gaud) Gardn. *Plant Physiol* 95: 95-753.

Lindblad, P. , and Bergman, B. (1989) Occurrence and localization of phycoerythrin in symbiotic *Nostoc* of *Cycas revoluta* and in the free-living isolated *Nostoc* 7422. *Plant Physiol* 89: 89-783.

Lindblad, P. , and Bergman, B. (1990) The cycad-cyanobacterial symbiosis. In: Rai, A. N. (Ed.) *Handbook of Symbiotic Cyanobacteria*. CRC Press, Boca Raton, Florida, FL, USA. pp. 137-159.

Lindblad, P. , Bergman, B. , Hofsten, A. V. , Höllbom, L. , and Nylund, J. E. (1985) The cyanobacterium-*Zamia* symbiosis: An ultrastructural study. *New Phytol* 101: 101-707.

Lindblad, P. , Höllbom, L. , and Bergman, B. (1985) The cyanobacterium-*Zamia* symbiosis: C₂H₂-reduction and heterocyst frequency. *Symbiosis* 1: 1-19.

Lindblad, P. , Haselkorn, R. , Bergman, B. , Nierzwicki-Bauer, S. A. (1989) Comparison of DNA restriction fragment length polymorphisms of *Nostoc* strains in and from cycads. *Arch Microbiol* 152: 152-220.

Lockhart, C. M. , Rowell, P. , and Stewart, W. D. P. (1978) Phytohaemagglutinins from the nitrogen-fixing lichens *Peltigera canina* and *P. polydactyla*. *FEMS Microbiol Lett* 3: 3-127.

Logsdon, J. M. Jr. (1998) The recent origin of spliceosomal introns revisited. *Curr opin Genet Dev* 8: 8-637.

Lohtander, K. , Oksanen, I. , Rikkinen, J. (2003) Genetic diversity of green algal and cyanobacterial photobionts in *Nephroma* (*Peltigerales*). *Lichenologist* 35: 35-325.

Lucas, I. A. N. (1991) Symbionts of the tropical Dinophysiales (Dinophyceae). *Ophelia* 33: 33-213.

Lücking, R. (2008) Folicolous lichenized fungi. *Flora Neotropica Monograph* 103: 103-111.

Lücking, R. , Lowrey, J. D. , Sikaroodi, M. , Gillevet, P. M. , Chaves, J. L. , Sipman, H. J. M. , and Bungartz, F. (2009) Do lichens domesticate photobionts like farmers domesticate crops? Evidence from a previously unrecognized lineage of filamentous cyanobacteria. *Am J Bot* 96: 96-1409.

Lumpkin, T. A. , Zimmerman, W. J. , and Watanabe, I. (1991) The *Anabaena*-*Azolla* symbiosis: Diversity and relatedness of neotropical host taxa. *Plant Soil* 137: 137-167.

Lutzoni, F. , Pagel, M. , and Reeb, V. (2001) Major fungal lineages are derived from lichen symbiotic ancestors. *Nature (London)* 411: 411-937.

Lyimo, T. J. (2011) Distribution and abundance of the cyanobacterium *Richelia intracellularis* in the coastal waters of Tanzania. *J Ecol Nat Environ* 3: 3-85.

Lykke-Andersen, J. , Aagaard, C. , Semionenkova, M. , and Garrett, R. A. (1997) Archaeal introns: Splicing, intercellular mobility and evolution. *Trends Biochem Sci* 22: 22-326.

Lyons, B. , Nadkarni, N. M. , and North, M. P. (2000) Spatial distribution and succession of epiphytes of *Tsuga heterophylla* (western hemlock) in an old-growth Douglas-fir forest. *Can J Bot* 78: 78-957.

Maass, W. S. G. (1980) *Erioderma pedicellatum* in North America: A case study of a rare and endangered lichen. *Proc N S Inst Sci* 30: 30-69.

Maass, W. S. G. (1983) New Observations on *Erioderma* in North America. *Nordic J Bot* 3: 3-567.

Madan, A. P. , and Nierzwicki-Bauer, S. A. (1993) In situ detection of transcripts for ribulose-1,5-bisphosphate carboxylase in cyanobacterial heterocysts. *J Bacteriol* 175: 175-7301.

Mague, T. , Weare, N. , and Holm-Hansen, O. (1974) Nitrogen fixation in the North Pacific Ocean. *Mar Biol* 24: 24-109.

Marx, M. , and Peveling, E. (1983) Surface receptors in lichen symbionts visualized by fluorescence microscopy after use of lichens. *Protoplasma* 114: 114-152.

Mattfeld, J. (1933) Weiteres zur Kenntnis der *Gunnera herteri* Osten. *Ostenia (Coleccion de Trabajos Botanicos)*, Montevideo, pp. 102-118.

Mazel, D. , Houmard, J. , Castets, A. M. , Tandeau de Marsac, N. (1990) Highly repetitive DNA sequences in cyanobacterial genomes. *J Bacteriol* 172: 172-2755.

McCowen, S. M. , MacArthur, L. , and Gates, J. E. (1987) *Azolla* fern lectins that specifically recognize endosymbiotic cyanobacteria. *Curr Microbiol* 14: 14-329.

McCune, B. (1993) Gradients in epiphyte biomass in three *Pseudotsuga-Tsuga* forests of different ages in western Oregon and Washington. *Bryologist* 96: 96-405.

McCune, B. (1994) Using epiphyte litter to estimate epiphyte biomass. *Bryologist* 97: 97-396.

McCune, B. , Amsberry, K. A. , Camacho, F. J. , Clery, S. , Cole, C. , Emerson, C. , Felder, G. , French, P. , Greene, D. , Harris, R. , Hutten, M. , Larson, B. , Lesko, M. , Majors, S. , Markwell, T. , Parker, G. G. , Pendergrass, K. , Peterson, E. B. , Peterson, E. T. , Platt, J. , Proctor, J. , Rambo, T. , Rosso, A. , Shaw, D. , Turner, R. , and Widmer, M. (1997) Vertical profile of epiphytes in a Pacific old-growth forest. *Northwest Science* 71: 71-145.

McLuckie, J. (1922) Studies in symbiosis. The apogeotropic roots of *Macrozamia spiralis* and their physiological significance. *Proc Linn Soc New South Wales* 47: 47-319.

Meeks, J. C. (1990) Cyanobacterial-bryophyte associations. In: Rai, A. N. (Ed.) *Handbook of Symbiotic Cyanobacteria*. CRC Press, Boca Raton, Florida, FL, USA. pp. 43-63.

Meeks, J. C. (1998) Symbiosis between nitrogen-fixing cyanobacteria and plants. *BioScience* 48: 48-266.

Meeks, J. C. , Joseph, C. M. , and Haselkorn, R. (1988) Organization of the *nif* genes in cyanobacteria in symbiotic association with *Azolla* and *Anthoceros*. *Arch Microbiol* 150: 150-161.

Meeks, J. C. , Enderlin, C. S. , Joseph, C. M. , Chapman, J. S. , and Lollar, M. W. L. (1985) Fixation of $[^{15}\text{N}]\text{N}_2$ and transfer of fixed nitrogen in the *Anthoceros-Nostoc* symbiotic association. *Planta* 164: 164-406.

Meeks, J. C. , Steinberg, N. A. , Enderlin, C. S. , Joseph, C. M. , and Peters, G. A. (1987) *Azolla-Anabaena* relationship. XIII. Fixation of $[^{15}\text{N}]\text{N}_2$. *Plant Physiol* 84: 84-883.

Mellor, R. B. , Gadd, G. M. , Rowell, P. , and Stewart, W. D. P. (1981) A phytohaemagglutinin from the *Anabaena azollae* symbiosis. *Biochem Biophys Res Comm* 99: 99-1348.

Miao, V. P. W. , Rabenau, A. , and Lee, A. (1997) Cultural and molecular characterization of photobionts of *Peltigera membranacea*. *Lichenologist* 29: 29-571.

Michel, F. , Umesono, K. , and Ozeki, H. (1989) Comparative and functional anatomy of group II catalytic introns—a review. *Gene* 82: 82-85.

Miehe, H. (1924) Entwicklungsgeschichtliche untersurbung der algensymbiose bei *Gunnera macrophylla* Bl. *Flora* 117: 117-211.

Moe, R. (1997) *Verrucaria taveresiae* sp. nov., a marine lichen with a brown algal photobiont. *Bull Calif Lichen Soc* 4: 4-7.

Molina, M. C. , and Vicente, C. (1993) Loss of photoergonic condition of *Xanthoria parietina* photobiont effected by an algalbinding protein isolated from the same lichen species. In: Sato, V. , Ishida, S. , and Ishikawa, H. (Eds.) *Endocytobiology*. Tübingen University Press, Tübingen, Germany. pp. 69-74.

Molina, M. C. , and Vicente, C. (1995) Correlationships between enzymatic activity of lectins, putrescine content and chloroplast damage in *Xanthoria parietina* photobionts. *Cell Adhesion Commun* 3: 3-11.

Molina, M. C. , and Vicente, C. (1996) Ultrastructural deterioration of *Xanthoria parietina* (L.) Th. Fr. phycobiont induced by a *Xanthoria* lectin. *Phyton (Austria)* 36: 36-197.

Molina, M. C. , and Vicente, C. (2000) Purification and characterization of two isolectins with arginase activity from the lichen *Xanthoria parietina*. *J Biochem Mol Biol* 33: 33-300.

Molina, M. C. , Bajon, C. , Sauvanet, A. , Robert, D. , and Vicente, C. (1998b) Detection of polysaccharides and ultrastructural modification of the photobiont cell wall produced by two arginase isolectins from *Xanthoria parietina*. *J Plant Res.* 111: 111-191.

Molina, M. C. , Muñiz, E. , and Vicente, C. (1993) Enzymatic activities of algal-binding protein and its algal cell wall receptor in the lichen *Xanthoria parietina*. An approach to the parasitic basis of mutualism. *Plant Physiol Biochem* 31: 31-131.

Molina, M. C. , Stocker-Wörgötter, E. , Türk, R. , and Vicente, C. (1998a) Secreted, glycosylated arginase from *Xanthoria parietina* thallus induces loss of cytoplasmic material from *Xanthoria* photobionts. *Cell Adhesion Commun* 6: 6-481.

Molina, M. C. , Vicente, C. , Pedrosa, M. M. , and Muniz, E. (1996) Binding of a labeled lectin from the lichen *Xanthoria parietina* to its own phycobiont and analysis of its enzymatic activity. *Phyton (Austria)* 36: 36-145.

Monteiro, F. M. , Follows, M. J. , and Dutkiewicz, S. (2010) Distribution of diverse nitrogen fixers in the global ocean. *Global Biogeochem Cycles* 24: GB3017. doi:10.1029/2009GB003731

Moore, A. W. (1969) *Azolla*: Biology and agronomic significance. *Bot Rev* 35: 35-117.

Moore, M. J. , Soltis, P. S. , Bell, C. D. , Burleigh, J. D. , and Soltis, D. E. (2010) Phylogenetic analysis of 83 plastid genes further resolves the early diversification of eudicots. *Proc Natl Acad Sci USA* 107: 107-4623.

Munro, M.H.G. , Blunt, J.W. , Dumdei, E.J. , Hickford, S.J.H. , Lill, R.E. , Li, S. , Battershill, C.N. , and Duckworth, A.R. , (1999) The discovery and development of marine compounds with pharmaceutical potential. *J Biotechnol* 70: 70-75.

Myllys, L. M. , Stenroos, S. , Thell, A. , and Kuusinen, Y. M. (2007) High cyanobiont selectivity of epiphytic lichens in old growth boreal forest of Finland. *New Phytol* 173: 173-621.

Nash, T. H. III (1996) Nitrogen, its metabolism and potential contribution of ecosystems. In: Nash, T. H. III (Ed.) *Lichen Biology*. Cambridge University Press, Cambridge, UK. pp. 121-135.

Nash, T. H. III (Ed.) (1996) *Lichen Biology*. Cambridge University Press, Cambridge, UK.

Nathanielsz, C. P. , and Staff, I. A. (1975a) A mode of entry of blue-green algae into the apogeotropic roots of *Macrozamia communis*. *Am J Bot* 62: 62-232.

Nathanielsz, C. P. , and Staff, I. A. (1975b) On the occurrence of intracellular blue-green algae in cortical cells of the apogeotropic roots of *Macrozamia communis* L. Johnson. *Ann Bot* 39: 39-363.

Neitlich, P. N. , and McCune, B. (1997) Hotspots of epiphytic lichen diversity in two young managed forests. *Conser Biol* 11: 11-172.

Neuman, D. (1977) Ultrastrukturelle Untersuchungen zur Symbiose von Cyanophyceen mit Cycadeen (*Cycas circinnalis* L., *Zamia furfuraceae* L.). *Biochem Physiol Pflanzen* 171: 171-313.

Neumüller, M. , and Bergman, B. (1981) The ultrastructure of *Anabaena azollae* in *Azolla pinnata*. *Physiol Plant* 51: 51-69.

Newcomb, E. H. , and Pugh, T. D. (1975) Blue-green algae associated with ascidians of the Great Barrier Reef. *Nature (London)* 253: 253-533.

Newton, J. W. , and Cavins, J. F. (1976) Altered nitrogenous pools induced by the *Azolla-Anabaena azollae* symbiosis. *Plant Physiol* 58: 58-798.

Newton, J. W. , and Herman, A. I. (1979) Isolation of cyanobacteria from the aquatic fern, *Azolla*. *Arch Microbiol* 120: 120-161.

Nieboer, E. , McFarlane, J. D. , and Richardson, D. H. S. (1984) Modification of plant cell buffering capacities by gaseous air pollutants. In: Koziol, M. , and Whatley, F. R. (Eds.) *Gaseous Air Pollutants and Plant Metabolites*, Butterworths, London, UK. pp. 313-333.

Nierzwicki-Bauer, S. A. , and Haselkorn, R. (1986) Differences in mRNA levels in *Anabaena* living freely or in symbiotic association with *Azolla*. *Embo J* 5: 5-29.

Nilsen, T. W. (2003) The spliceosome: The most complex macromolecular machine in the cell? *Bioessays* 25: 25-1147.

Nilsson, M. , Bergman, B. , and Rasmussen, U. (2000) Cyanobacterial diversity in geographically related and distant host plants of the genus *Gunnera*. *Arch Microbiol* 173: 173-197.

Nilsson, M. , Rasmussen, U. , and Bergman, B. (2006) Cyanobacterial chemotaxis to extracts of host and nonhost plants. *FEMS Microbiol Ecol* 55: 55-382.

Norstog, K. J. , and Nicholls, T. J. (1997) *The Biology of the Cycads*. Cornell University Press, Ithaca, NY, USA.

Nyati, S. , Beck, A. , and Honegger, R. (2007) Fine structure and phylogeny of green algal photobionts in the microfilamentous genus *Psoroglaena* (Verrucariaceae, lichen-forming ascomycetes). *Plant Biol* 9: 9-390.

O'Brien, H. E. , Miadlikowska, J. , and Lutzoni, F. (2005) Assessing host specialization in symbiotic cyanobacteria associated with four closely related species of the lichen fungus *Peltigera*. *Eur J Phycol* 40: 40-363.

Obukowicz, M. , Schaller, M. , and Kennedy, G. S. (1981) Ultrastructure and phenolic histochemistry of the *Cycas revoluta-Anabaena* symbiosis. *New Phytol* 87: 87-751.

Oksanen, I. (2004) Specificity in cyanobacterial lichen symbiosis and bioactive metabolites (ethylene and microcystins). *Dissertat Biocentri Viikki Univ. Helsingiensis* 23: 23-101.

Oksanen, I. , Lohlander, K. , Sivonen, K. , and Rikkinen, J. (2004) Repeat-type distribution in trnL intron does not correspond with species phylogeny: Comparison of the genetic markers 16S rRNA and trnL intron in heterocystous cyanobacteria. *Int J Syst Evol Microbiol* 54: 54-765.

Orr, J. , and Haselkorn, R. (1982) Regulation of glutamine synthetase activity and synthesis in free-living and symbiotic *Anabaena* spp. *J Bacteriol* 152: 152-626.

Osborne, B. A. , Cullen, A. , Jones, P. W. , and Campbell, G. J. (1992) Use of nitrogen by the *Nostoc-Gunnera tinctoria* (Molina) Mirbel symbiosis. *New Phytol* 120: 120-481.

Otálora, M. A. G. , Martínez, I. , O'Brien, H. , Molina, M. C. , and Aragón, G. (2010) Multiple origins of high reciprocal symbiotic specificity at an intercontinental spatial scale among gelatinous lichens (Collemataceae; Lecanoromycetes). *Mol Phyl Evol* 56: 56-1089.

Ott, S. (1988) Photosymbiodemes and their development in *Peltigera venosa*. *Lichenologist* 20: 20-361.

Ow, M. C. , Gantar, M. , and Elhai, J. (1999) Reconstitution of a cycad-cyanobacterial association. *Symbiosis* 27: 27-125.

Page, R. D. , and Hafner, M. S. (1996) Molecular phylogenies and host-parasite cospeciation: Gophers and lice as a model system. In: Harvey, P. H. , Leigh, A. J. , Brown, J. , Smith, M. and Nee, S. (Eds.) *New Uses for New Phylogenies*. Oxford University Press, New York, NY, USA. pp. 255-272.

Pandey, K. D. , Kashyap, A. K. , and Gupta, R. K. (1992) Nitrogen fixation by cyanobacteria associated with moss communities in Schimacher oasis, Antarctica. *Israel J Bot* 41: 41-187.

Papaefthimiou, D. , Hrouzek, P. , Mugnai, M. A. , Lukesova, A. , Turicchia, S. , Rasmussen, U. , and Ventura, S. (2008) Differential patterns of evolution and distribution of symbiotic behaviour in nostocacean cyanobacteria. *Syst Evol Microbiol* 58: 58-553.

Paquin, B. , Kathe, S. D. , Nierzwicki-Bauer, S. A. , and Shub, D. A. (1997) Origin and evolution of group I introns in cyanobacterial tRNA genes. *J Bacteriol* 179: 179-6798.

Parsons, R. (2002) Nodule function and regulation in the *Gunnera-Nostoc* symbioses. *Proc R Irish Acad* 102: 102-141.

Paulsrud, P. , and Lindblad, P. (1998) Sequence variation of the tRNA^{Leu} (UAA) intron as a marker for genetic diversity and specificity of symbiotic cyanobacteria in some lichens. *Appl Environ Microbiol* 64: 64-310.

Paulsrud, P. , Rikkinen, J. , and Lindblad, P. (1998) Cyanobiont specificity in some *Nostoc*-containing lichens and in a *Peltigera aphthosa* photosymbiodemes. *New Phytol* 139: 139-517.

Paulsrud, P. , Rikkinen, J. , and Lindblad, P. (2000) Spatial patterns of photobiont diversity in some *Nostoc*-containing lichens. *New Phytol* 146: 146-291.

Paulsrud, P. , Rikkinen, J. , and Lindblad, P. (2001) Field investigations on cyanobacterial specificity in *Peltigera aphthosa*. *New Phytol* 152: 152-217.

Pawlik, J. R. , Chanas, B. , Toonen, R. J. , and Fenical, W. (1995) Defenses of Caribbean sponges against predatory reef fish. I. Chemical deterency. *Mar Ecol Prog Ser* 127: 127-183.

Perkins, S.K. , and Peters, G. A. (1992) The Azolla-Anabaena symbiosis: Endophyte continuity in the Azolla life-cycle is facilitated by epidermal trichomes. I. Partitioning of the endophytic Anabaena into developing sporocarps. *New Phytol* 123: 123-153.

Peters, G. A. (1975) The Azolla-Anabaena relationship III. Studies of metabolic capabilities and a further characterization of the symbiont. *Arch Microbiol* 103: 103-113.

Peters, G. A. (1991) Azolla and other plant-cyanobacteria symbioses: Aspects of form and function. *Plant Soil* 137: 137-225.

Peters, G. A. , and Calvert, H. E. (1983) The Azolla-Anabaena symbiosis. In: Gof, T. L. J. (Ed.) *Algal Symbiosis*. Cambridge University Press, New York, NY, USA. pp. 109-145.

Peters, G. A. , and Mayne, B. C. (1974a) The Azolla, Anabaena azollae relationship. I. Initial characterization of the association. *Plant Physiol* 53: 53-813.

Peters, G. A. , and Mayne, B. C. (1974b) The Azolla, Anabaena azollae relationship. II. Localization of nitrogenase activity as assayed by acetylene reduction. *Plant Physiol* 53: 53-820.

Peters, G. A. , and Perkins, S. K. (1993) The Azolla-Anabaena symbiosis: Endophyte continuity in the Azolla-life cycle is facilitated by epidermal trichomes. II. Re-establishment of the symbiosis following gametogenesis and embryogenesis. *New Phytol* 123: 123-165.

Peters, G. A. , Toia, R. E. Jr. , and Lough, S. M. (1977) Azolla-Anabaena azollae relationship. V. $^{15}\text{N}_2$ fixation, acetylene reduction, and H_2 production. *Plant Physiol* 59: 59-1021.

Peters, G. A. , Toia, R. E. Jr. , Levine, N. J. , and Raveed, D. (1978) Azolla-Anabaena azollae relationship. VI. Morphological aspects of the association. *New Phytol* 80: 80-583.

Petit, P. (1982) Phytolectins from the nitrogen-fixing lichen *Peltigera horizontalis*: The binding pattern of protein extract. *New Phytol* 91: 91-705.

Petit, P. , Lallemand, R. and Savoye, D. (1983) Purified phytolectin from the lichen *Peltigera canina* var. *canina* which binds to the phycobiont cell walls and its use as a cytochemical marker in situ. *New Phytol* 94: 94-103.

Piercey-Normore, M. D. , and DePriest, P. T. (2001) Algal switching among lichen symbioses. *Am J Bot* 88: 88-1490.

Pieterse, A. H. , de Lange , and van Vliet, J. P. (1977) A comparative study of Azolla in the Netherlands. *Acta Bot Neerl* 26: 26-433.

Pike, L. H. (1978) The importance of epiphytic lichens in mineral cycling. *Bryologist* 81: 81-247.

Pile, A. J. , Patterson, M. R. , and Witman, J. D. (1996) In situ grazing on plankton <10 μm by the boreal sponge *Mycale lingua*. *Mar Ecol Progr Ser* 141: 141-195.

Planelles, V. , and Legaz, M. E. (1987) Purification and some properties of the secreted arginase of the lichen *Evernia prunastri* and its regulation by usnic acid. *Plant Sci* 51: 51-59.

Plazinski, J. , Franche, C. , Liu, C.-C. , Lin, T. , Shaw, W. , Gunning, B. E. S. , and Rolfe, B. G. (1988) Taxonomic status of *Anabaena azollae*: An overview. *Plant Soil* 108: 108-185.

Precht, J. , Kneip, C. , Lockhart, P. , Wenderoth, K. , and Maier, U.-G. (2004) Intracellular sphaeroid bodies of *Rhopalodia gibba* have nitrogen-fixing apparatus of cyanobacterial origin. *Mol Biol Evol* 21: 21-1477.

Preston, C. M. , Wu, K. Y. , Molinski, T. F. , and DeLong, E. F. (1996) A psychrophilic crenarchaeon inhabits a marine sponge: *Crenarchaeum symbiosum* gen. nov., sp. nov. *Proc Natl Acad Sci USA* 93: 93-6241.

Quilhot, W. , Piovano, M. , Chamy, M. C. , and Garbarino, J. A. (1995) Studies on Chilean lichens. XXII. Secondary products from *Degelia Gayana*. *Lichenologist* 27: 27-405.

Quilhot, W. , Rubio, C. , Fernandez, E. , and Hidalgo, M. E. (2002) Efectos de la radiacion UV solar en la acumulacion de 1'-cloropannarina en *Erioderma leylandii* (Pannariaceae, Ascomycotina liquenizado), Laguna San Rafael, Aisen, Chile [Effects of UV solar radiation on the accumulation of 1'-chloropannarin in *Erioderma leylandii* (Pannariaceae, lichenized Ascomycotina) Laguna San Rafael, Aisen, Chile]. *Boletín del Museo Nacional de Historia Natural, Chile* 51: 51-75.

Radies, D. N. , and Coxson, D. S. (2004) Macrolichen colonization on 120-140 year old *Tsuga heterophylla* in wet temperate rainforests of central-interior British Columbia: A comparison of lichen response to even-aged versus old-growth stand structures. *Lichenologist* 36: 36-235.

Rai, A. N. (1990) *CRC Handbook of Symbiotic Cyanobacteria*. CRC Press, Boca Raton, Florida, FL, USA.

Rai, A. N. , and Bergman, B. (2002) Cyanolichens. *Proc R Irish Acad* 102B: 19-22.

Rai, A. N. , Söderbäck, E. , and Bergman, B. (2000) Cyanobacterium-plant symbioses. *New Phytol* 147: 147-449.

Rai, A. N. , Borthakur, M. , Singh, S. , and Bergman, B. (1989) Anthoceros-Nostoc symbiosis: Immunoelectronmicroscopic localization of nitrogenase, glutamine synthetase, phycoerythrin and ribulose-1,5-biphosphate carboxylase/oxygenase in the cyanobiont and the cultured (free-living) isolate Nostoc 7801. *J Gen Microbiol* 135: 135-385.

Rambold, G. , Friedl, T. , and Beck, A. (1998) Photobionts in lichens: Possible indicators of phylogenetic relationships? *Bryologist* 101: 101-392.

Ran, L. , Larsson, J. , Vigil-Stenman, T. , Nylander, J. A. A. , Ininbergs, K. , Zheng, W-W. , Lapidus, A. , Lowry, S. , Haselkorn, R. , and Berman, B. (2010) Genome erosion in a nitrogen-fixing vertically transmitted endosymbiotic multicellular cyanobacterium. *PLoS ONE* 5: e11486. doi:10.1371/journal.pone.0011486

Rasmussen, U. , and Svenning, M. M. (1998) Fingerprinting of cyanobacteria based on PCR with primers derived from short and long tandemly repeated repetitive sequences. *Appl Environ Microbiol* 64: 64-265.

Rasmussen, U. , and Svenning, M. (2001) Characterisation by genotypic methods of symbiotic Nostoc strains isolated from five species of *Gunnera*. *Arch Microbiol* 176: 176-204.

Rasmussen, U. , Johansson, C. , and Bergman, B. (1994) Early communication in the *Gunnera-Nostoc* symbiosis: Plant-induced cell differentiation and protein synthesis in the cyanobacterium. *Mol Plant-Microbe Interact* 7: 7-696.

Rasmussen, U. , Johansson, C. , Renglin, A. , Peterson, C. , and Bergman, B. (1996) A molecular characterization of the *Gunnera-Nostoc* symbiosis: Comparison with the *Rhizobium*-plant and *Agrobacterium*-plant interactions. *New Phytol* 133: 133-391.

Ray, T. B. , Mayne, B. C. , Toia, R. E. Jr. , and Peters, G. A. (1979) Azolla-Anabaena relationship VIII. Photosynthetic characterization of the association and individual partners. *Plant Physiol* 64: 64-791.

Ray, T. B. , Peters, G. A. , Toia, R. E. Jr. , and Mayne, B. C. (1978) Azolla-Anabaena relationship VII. Distribution of ammonia-assimilating enzymes, protein, and chlorophyll between host and symbiont. *Plant Physiol* 62: 62-463.

Reinke, J. (1872) Parasitische Anabaena in Wurzeln der Cycadeen. *Gott Nachr* 107.

Reiswig, H. M. (1971) Particle feeding in natural populations of three marine demosponges. *Biol Bull* 141: 141-568.

Reiswig, H. (1974) Water transport, respiration and energetics of three tropical marine sponges. *J Exp Mar Biol Ecol* 14: 14-231.

- Renner, B. , and Galloway, D. J. (1982) Photosymbiodemes in *Pseudocypbellaria* in New Zealand. *Mycotaxon* 16: 16-197.
- Renzaglia, K. S. (1982) A comparative developmental investigation of the gametophyte generation in the Metzgeriales (Hepatophyta). *Bryophyt Bibl* 24: 24-31.
- Renzaglia, K. S. , Duff, R. J. , Nickrent, D. L. , and Garbary, D. (2000) Vegetative and reproductive innovations of early land plants: Implications for a unified phylogeny. *Trans R Soc B London* 355: 355-769.
- Rhoades, F. R. (1995) In: Lowman, N. D. , and Nadkarni, N. M. (Eds.) *Forest Canopies*. Academic Press, Toronto, Ontario, Canada. pp. 353-408.
- Richardson, D. H. S. , and Cameron, R. P. (2004) Cyanolichens: Their response to pollution and possible management strategies for their conservation in northeastern North American *Naturalist* 11: 11-21.
- Ridley, C. P. , Faulkner, D. J. , and Haygood, M. G. (2005) Investigation of *Oscillatoria spongellae*-dominated bacterial communities in four dictyoceratid sponges. *Appl Environ Microbiol* 71: 71-7366.
- Rikkinen, J. (2003) Ecological and evolutionary role of photobiont-mediated guilds in lichens. *Symbiosis* 34: 34-99.
- Rikkinen J. (2004) Ordination analysis of tRNA^{Leu}(UAA) intron sequences from lichen-forming *Nostoc* strains and other cyanobacteria. *Symbolae Botanicae Upsalienses* 34: 34-377.
- Rikkinen, J. , and Virtanen, V. (2008) Genetic diversity in cyanobacterial symbionts of thalloid bryophytes. *J Exp Bot* 59: 1013-1021. doi: 10.1093/jxb/em003.
- Rikkinen, J. , Oksanen, I. , and Lohtander, K. (2002) Lichen guilds share related cyanobacterial symbionts. *Science* 297: 357.
- Rippka, R. , Deruelles, J. , Waterbury, J. B. , Herdman, M. , and Stanier, R. Y. (1979) Generic assignments, strain histories and properties of pure cultures of cyanobacteria. *J Gen Microbiol* 111: 111-211.
- Robertson, A. (1998) The boreal felt lichen, *Erioderma pedicellatum* (Hue) P. M. Jorg , in Newfoundland, Report to Department of Forest Resources and Agrifoods, Government of Newfoundland and Labrador, St. Johns. pp. 63.
- Rodgers, G. A. , and Stewart, W. D. P. (1977) The cyanophyte-hepatic symbiosis. I. Morphology and physiology. *New Phytol* 78: 78-441.
- Rose, F. (1976) Lichenological indicators of age and environmental continuity in woodlands. In: Brown, D. H. , Hawksworth, D. L. , and Bailey, R. H. (Eds.) *Lichenology: Progress and Problems*. Academic Press, London, UK. pp. 279-307.
- Rose, F. (1988) Phytogeographical and ecological aspects of Lobarina communities in Europe. *Bot J Linn Soc* 96: 96-169.
- Rosbach, M. , and Lambrecht, S. (2006) Lichens as biomonitors: Global, regional and local aspects. *Croatica Chemica Acta* 79: 79-119.
- Rouhiainen, L. , Sivonen, K. , Buikema, W. J. , and Haselkorn, R. (1995) Characterization of toxin-producing cyanobacteria by using an oligonucleotide probe containing a tandemly repeated heptamer. *J Bacteriol* 177: 177-6021.
- Rowan, R. (1998) Diversity and ecology of zooxanthellae on coral reefs. *J Phycol* 34: 34-407.
- Rudi, K. , and Jakobsen, K. S. (1997) Cyanobacterial tRNA^{Leu} (UAA) group I introns have polyphyletic origin. *FEMS Microbiol Lett* 156: 156-293.
- Rudi, K. , and Jakobsen, K. S. (1999) Complex evolutionary patterns of tRNA^{Leu} (UAA) group I introns in cyanobacterial radiation. *J Bacteriol* 181: 181-3445.
- Rudi, K. , Fossheim, T. , and Jakobsen, K. S. (2002) Nested evolution of a tRNA^{Leu} (UAA) group I intron by both horizontal intron transfer and recombination of the entire tRNA locus. *J Bacteriol* 184: 184-666.
- Rützler, K. (1985) Association between Caribbean sponges and photosynthetic organisms. In: Rützler, K. (Ed.) *New Perspectives in Sponge Biology*, Smithsonian Institution Press, Washington, D. C. USA. pp. 455-466.
- Sacristán, M. , Millanes, A. M. , Legaz, M. E. , and Vicente, C. (2006) A lichen lectin specifically binds to the α -1,4-polygalactoside moiety of urease located in the cell wall of homologous algae. *Plant Signal Behav* 1: 1-23.
- Sacristán, M. , Millanes, A. M. , Fontaniella, B. , Legaz, M. E. , and Vicente, C. (2008) A first attempt to elucidate amino acid sequence of some lichen lectins. *Phyton (Austria)* 77: 77-253.
- Sacristón, M. , Vivas, M. , Millanes, A. M. , Fontaniella, B. , Vicente, C. , and Legaz, M. E. (2007) The recognition pattern of green algae by lichenized fungi can be extended to lichens containing cyanobacterium as photobiont. In: Mendez-Vilas, A. (Ed.) *Communicating Current Research and Educational Topics and Trends in Applied Microbiology*. Formatex Research Center, Badajoz, Spain pp. 213-219.
- Sanders, W. B. , Moe, R. L. , and Ascaso, C. (2004) The intertidal marine lichen formed by the pyrenomycetous fungus *Verrucaria tavaresiae* and the brown alga *Pteroderma maculiforme* (Phaeophyceae): Thallus organization and symbiont interaction. *Am J Bot* 91: 91-511.
- Sanders, W. B. , Moe, R. L. , and Ascaso, C. (2005) Ultrastructural study of the brown alga *Pteroderma maculiforme* (Phaeophyceae) in the free-living state and in lichen symbiosis with the intertidal marine fungus *Verrucaria tavaresiae* (Ascomycotina). *Eur J Phycol* 40: 40-353.
- Saldanha, R. , Mohr, G. , Belfort, M. , and Lambowitz, A. M. (1993) Group I and group II introns. *Faseb J* 7: 7-15.
- Santavy, D. L. , Willenz, P. , and Colwell, R. R. (1990) Phenotypic study of bacteria associated with the Caribbean sclerosponge *Ceratoporella nicholsoni*. *Appl Environ Microbiol* 56: 56-1750.
- Schacht, H. (1853) Beitrag zur Entwicklungs-Geschichte der Wurzel. *Flora* 17: 17-257.
- Scharek, R. , Latasa, M. , Karl, D. M. , and Bidigare, R. R. (1999a) Temporal variations in diatom abundance and downward vertical flux in the oligotrophic North Pacific gyre. *Deep Sea Res* 46: 1051-1075. doi:10.1016/S0967-0637(98)00102-2
- Scharek, R. , Tupas, L. M. , and Karl, D. M. (1999b) Diatom fluxes to the deep sea in the oligotrophic North Pacific gyre at Station ALOHA. *Mar Ecol Prog Ser* 182: 55-67. doi:10.3354/meps182055
- Schaede, R. (1951) Über die Blaualgensymbiose von *Gunnera*. *Planta* 39: 39-154.
- Schaede, R. (1962) *Die Pflanzlichen Symbiosen*. Gustav Fischer Verlag, Stuttgart, Germany.
- Scherrer, S. , and Honegger, R. (2003) Inter- and intraspecific variation of homologous hydrophobin (H1) gene sequences among *Xanthoria* spp. (lichen-forming ascomycetes). *New Phytol* 158: 158-375.
- Scherrer, S. , De Vries, O. M. H. , Dudler, R. , Wessels, J. G. H. , and Honegger, R. (2000) Interfacial self-assembly of fungal hydrophobins in the lichen-forming ascomycete *Xanthoria parietina* and *X. ectaneoides*. *Fungal Genet Biol* 30: 30-81.
- Scherrer, S. , Haisch, A. , and Honegger, R. (2002) Characterization and expression of XPH1, the hydrophobin gene of the lichen-forming ascomycete *Xanthoria parietina*. *New Phytol* 154: 154-175.
- Schindler, A.K. (1905) Haloragaceae. In: Engler, A. *Das Pflanzenreich* 4: 225.
- Schmidt, E. W. , Obratova, A.Y. , Davidson, S. K. , Faulkner, D. J. , and Haygood, M. G. (2000) Identification of the antifungal peptide-containing symbiont of the marine sponge *Theonella swinhoei* a novel Delta-Proteobacterium *Candidatus Enttheonella palauensis*. *Mar Biol* 136: 136-969.

- Schmidt, J. (1901) Ueber *Richelia intracellularis*, eine neue in Plankton-Diatomeen lebende Alge. *Hedwigia* 40: 40-112.
- Schüßler, A. , Meyer, T. , Gehrig, H. , and Kluge, M. (1997) Variations of lectin binding sites in extracellular glycoconjugates during the life cycle of *Nostoc punctiforme*, a potentially endosymbiotic cyanobacterium. *Eur J Phycol* 32: 32-233.
- Schüßler, A. , Martin, H. , Cohen, D. , Fitz, M. , and Wipf, D. (2006) Characterization of a carbohydrate transporter from symbiotic glomeromycotan fungi. *Nature (London)* 444: 444-933.
- Schütt, F. (1895) Peridineen der Plankton-Expedition. *Ergebnisse der Plankton-Expedition der Humboldt Stiftung* 4: 4-10.
- Seaward, M. R. D. , Lynds, A. , and Richardson, D. H. S. (1997) Lichens of Beaverbrook, Nova Scotia. *Proc Nova Scotia Institute of Science* 41: 41-93.
- Sherwood-Pike, M. A. (1985) *Pelicothallo* Dilcher, an overlooked fossil lichen. *Lichenologist* 17: 17-114.
- Shirley, B. W. (1996) Flavonoid biosynthesis: 'new' functions for an 'old' pathway. *Trends Plant Sci* 1: 1-377.
- Silvester, W. B. (1975) Endophyte adaptation in *Gunnera-Nostoc* symbiosis. In: Nutman, P. S. (Ed.) *Symbiotic Nitrogen Fixation in Plants*. Cambridge University Press, New York, NY, USA. pp. 521-538.
- Silvester, W. B. , and McNamara, P. J. (1976) The infection process and ultrastructure of the *Gunnera-Nostoc* symbiosis. *New Phytol* 77: 77-135.
- Silvester, W. B. , and Smith, D. R. (1969) Nitrogen fixation by *Gunnera-Nostoc* symbiosis. *Nature (London)* 224: 1231.
- Silvester, W. B. , Parsons, R. , and Watt, P. W. (1996) Direct measurement of release and assimilation of ammonia in the *Gunnera-Nostoc* symbiosis. *New Phytol* 132: 132-617.
- Sillett, S. C. (1995) Branch epiphyte assemblages in the forest interior and on the clearcut edge of 700-year old forest canopy in western Oregon. *Bryologist* 98: 98-301.
- Sillett, S. C. , and Goslin, M. N. (1999) Distribution of epiphytic macrolichens in relation to remnant trees in multiple-age Douglas-fir forest. *Can J For Res* 29: 29-1204.
- Sillett, S. C. , and Mc Cune, B. (1998) Survival and growth of cyanolichen transplants in Douglas-fir forest canopies. *Bryologist* 101: 101-120.
- Singh, R. S. , Bhari, R. , and Kaur, H. P. (2010) Mushroom lectins: Current status and future perspectives. *Critical Rev Biotechnol* 30: 99-126. doi:10.3109/07388550903365048
- Sipman, H. J. M. (2002) The significance of the northern Andes for lichens. *Bot Rev* 68: 68-88.
- Smith, D. C. (1980) Mechanisms of nutrient movement between lichen symbionts. In: Cook, C. B. , Pappas, P. W. , and Rudolph, E. D. (Eds.) *Cellular Interactions in Symbiosis and Parasitism*. Ohio State University Press, Ohio, USA. pp. 197-227.
- Snøeijls, P. , and Murasi, L. W. (2004) Symbiosis between diatoms and cyanobacterial colonies. *Vie Milieu* 54: 54-163.
- Söderback, E. , and Bergman, B. (1992) The *Nostoc-Gunnera megallanica* symbiosis: Phycobiliproteins, carboxysomes and Rubisco in the cyanobiont. *Physiol Plant* 84: 84-425.
- Söderback, E. , and Bergman, B. (1993) The *Nostoc-Gunnera* symbiosis: Carbon fixation and translocation. *Physiol Plant* 89: 89-125.
- Söderback, E. , Lindblad, P. , and Bergman, B. (1990) Developmental patterns related to nitrogen fixation in the *Nostoc-Gunnera megallanica* Lam. symbiosis. *Planta* 182: 182-355.
- Solereder, H. (1908) *Systemic Anatomy of the Dicotyledons*. Vol I. Revised D. H. Scott (1908) Clarendon Press, Oxford, UK.
- Solheim, B. , and Zielke, M. (2002) Associations between cyanobacteria and mosses. In: Rai, A. N. , Bergman, B. , and Rasmussen, U. (Eds.) *Cyanobacteria in Symbiosis*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 137-152.
- Sollins, P. , Grier, C. C. , McCorison, F. M. , Cromack Jr., K. , Fogel, R. , and Fredriksen, R. L. (1980) The internal element cycles of an old-growth Douglas-fir ecosystem in western Oregon. *Ecological Monographs* 50: 50-261.
- Spaink, H. P. , Solheim, B. , Wiggen, H. , Röberg, S. (2004) Associations between arctic cyanobacteria and mosses. *Symbiosis* 37: 37-169.
- Spanu, P. (1997) HCF-1, a hydrophobin from the tomato pathogen *Cladosporium fulvum*. *Gene* 193: 193-289.
- Spratt, E. R. (1911) Some observations on the life history of *Anabaena cycadeae*. *Ann Bot* 25: 25-369.
- Spratt, E. R. (1915) The root-nodules of the *Cycadaceae*. *Ann Bot* 29: 29-619.
- Stafford, H. A. (1997) Roles of flavonoids in symbiotic and defense functions in legume roots. *Bot Rev* 63: 63-127.
- Stein, W. E. , Harmon, G. D. and Hueber, F. M. (1993) Spongiophyton from the Lower Devonian of North America reinterpreted as a lichen. *Am J Bot* 80: 93.
- Stenroos, S. , Högnabba, F. , Myllys, L. , Hyvönen, J. , and Thell, A. (2006) High selectivity in symbiotic associations of lichenized ascomycetes and cyanobacteria. *Clastidics* 22: 22-230.
- Steinberg, N. A. , and Meeks, J. C. (1989) Photosynthetic CO₂ fixation and ribulose biphosphate carboxylase/oxygenase activity of *Nostoc* sp. strain UCD 7801 in symbiotic association with *Anthoceros punctatus*. *J Bacteriol* 171: 171-6227.
- Steinberg, N. A. , and Meeks, J. C. (1991) Physiological sources of reductant for nitrogen fixation activity in *Nostoc* sp. strain UCD 7801 in symbiotic association with *Anthoceros punctatus*. *J Bacteriol* 173: 173-7324.
- Steindler, L. , Huchon, D. , Avni, A. , and Ilan, M. (2005) 16S rRNA Phylogeny of sponge-associated cyanobacteria. *Appl Environ Microbiol* 71: 71-4127.
- Stewart, W. D. P. , and Rodgers, G. A. (1977) The cyanophyte-hepatic symbiosis. *New Phytol* 78: 78-459.
- Stock, P. A. , and Silvester, W. B. (1994) Phloem transport of recently fixed nitrogen in the *Gunnera-Nostoc* symbiosis. *New Phytol* 126: 126-259.
- Stocker-Wörgötter, E. (1995) Experimental cultivation of lichens and lichen symbionts. *Can J Bot* 73: S579-S589.
- Stocker-Wörgötter, E. , and Türk, R. (1990) Thallus formation of the cyanobacterial lichen *Peltigera didactyla* from soredia under laboratory conditions. *Bot Acta* 103: 103-315.
- Stocker-Wörgötter, E. , and Türk, R. (1994) Artificial resynthesis of the photosymbiodemes *Peltigera leucophlebia* under laboratory conditions. *Cryptogamic Bot* 4: 4-300.
- Strasburger, E. (1873) *Ueber Azolla*. Verlag von Ambr Abel., Leipzig, Germany.
- Subramaniam, A. , Yager, P. L. , Carpenter, E. J. , Mahaffey, C. , Bjorkman, K. , Cooley, S. , Kustka, A. B. , Montoya, J. P. , Sañudawilhelmy, S. A. , Shipe, R. , and Capone, D. G. (2008) Amazon River enhances diazotrophy and carbon sequestration in the tropical North Atlantic Ocean. *Proc Natl Acad Sci USA* 105: 105-10460.
- Subramanian, G. , and Malliga, P. (1988) Isolation of *Anabaena azollae* from the megasporocarp of *Azolla*. *Curr Sci* 57: 57-1352.

Summerfield, T. C. , and Eaton-Rye, J. J. (2006) *Pseudocypbellaria crocata*, *P. neglecta* and *P. perpetua* from Northern and Southern Hemispheres are a phylogenetic species and share cyanobionts. *New Phytol* 170: 170-597.

Summerfield, T. C. , Galloway, D. J. , and Eaton-Rye, J. J. (2002) Species of cyanolichens from *Pseudocypbellaria* with indistinguishable ITS sequences have different photobionts. *New Phytol* 155: 155-221.

Sundström, B. G. (1984) Observations on *Rhizosolenia clevei* Ostenfeld (Bacillariophyceae) and *Richelia intracellularis* Schmidt (Cyanophyceae). *Bot Mar* 27: 27-345.

Svenson, H. K. (1944) The new world species of *Azolla*. *Am Fern J* 34: 34-69.

Svenning, M. M. , Eriksson, T. , and Rasmussen, U. (2005) Phylogeny of symbiotic cyanobacteria within the genus *Nostoc* based on 16S rDNA sequence analysis. *Arch Microbiol* 183: 183-219.

Swanson, A. , and Fahselt, D. (1997) Effects of ultraviolet on polyphenolics of *Umbilicaria americana*. *Can J Bot* 75: 284-289.

Tagu, D. , Nasse, B. , and Martin, F. (1996) Cloning and characterization of hydrophobin-encoding cDNAs from the ectomycorrhizal basidiomycete *Pisolithus tinctorius*. *Gene* 168: 168-193.

Tapper, R. (1981) Direct measurement of translocation of carbohydrate in the lichen *Cladonia convoluta*, by quantitative autoradiography. *New Phytol* 89: 89-429.

Taylor, D. L. (1974) Symbiotic marine algae: Taxonomy and biological fitness. In: Vernberg, C. B. W. (Ed.) *Symbiosis in the Sea*. University of South Carolina Press, Columbia, USA. pp. 245-262.

Taylor, M. W. , Schupp, P. J. , de Nys, R. , Kjelleberg, S. , and Steinberg, P. D. (2005) Biogeography of bacteria associated with the marine sponge *Cymbastella concentrica*. *Environ Microbiol* 7: 7-419.

Taylor, T. N. , and Taylor, E. L. (1993) *The Biology and Evolution of Fossil Plants*. Prentice-Hall, Englewood Cliffs, NJ, USA.

Taylor, T. N. , Hass, H. , and Kerp, H. (1997) A cyanolichen from the Lower Devonian Rhynie Chert. *Am J Bot* 84: 84-992.

Tel-Or, E. , Sandovsky, T. , Kobiler, D. , Arad, C. , and Weinberg, R. (1983) The unique symbiotic properties of *Anabaena* in the water fern *Azolla*. In: Papegeorgiou, G. C. and Packer, L. (Eds.) *Photosynthetic Prokaryotes: Cell Differentiation and Function*. Elsevier Science, New York, NY, USA. pp. 303-314.

Thacker, R. W. (2005) Impacts of shading on sponge-cyanobacteria symbioses: A comparison between host-specific and generalist associations. *Integr Comp Biol* 45: 45-369.

Thacker, R. W. , and Starnes, S. (2003) Host specificity of the symbiotic cyanobacterium *Oscillatoria spongelliae* in marine sponges, *Dysidea* spp. *Marine Biol* 142: 142-643.

Thacker, R. W. , Becerro, M. A. , Lumbang, W. A. and Paul, V. J. (1998) Allelopathic interactions between sponges on a tropical reef. *Ecology* 79: 79-1740.

Thakur, N. L. , Hentschel, U. , Krasko, A. , Pabel, C. T. , Anil, A. C. , and Möller, W. E. G. (2003) Antibacterial activity of the sponge *Suberites domuncula* and its primmorphs: Potential basis for epibacterial chemical defense. *Aquatic Microbial Ecol* 31: 31-77.

Thompson, J. N. (1994) *The Coevolutionary Process*. University of Chicago Press, Chicago, Illinois, USA.

Tikhonovich, I. , Lutenberg, B. , and Prvorov, N. (2004) *Biology of Molecular Plant-Microbe Interactions*. Vol. 4, CPL Scientific Publishers Ltd. Berkshire, UK. pp. 633.

Tobin, A. K. , and Yamaya, T. (2001) Cellular compartmentation of ammonium assimilation in rice and barley. *J Exp Bot* 52: 52-591.

Tomaselli, L. , Margheri, M. C. , Giovannetti, L. , Sili, C. , and Carlozzi, P. (1988) The taxonomy of *Azolla* spp. cyanobionts. *Annali di Microbiologia* 38: 38-157.

Tønnesberg, T. , and Holtan-Hartwig, J. (1983) Phycotype pairs in *Nephroma*, *Peltigera* and *Lobaria* in Norway. *Nordic J Bot* 3: 681-688. doi:10.1111/j.1756-1051.1983.tb.01479.x

Towata, E. M. (1985) Mucilage glands and cyanobacterial colonization in *Gunnera kaalensis* (Haloragaceae). *Bot Gaz* 146: 146-156.

Trembley, M. L. , Ringli, C. , and Honegger, R. (2002) Differential expression of hydrophobins DGH1, DGH2, and DGH3 and immunolocalization of DGH1 in strata of the lichenized basidiocarp of *Dictyonema glabratum*. *New Phytol* 154: 154-185.

Trembley, M. L. , Ringli, C. , and Honegger, R. (2002a) Hydrophobins DGH1, DGH2, and DGH3 in the lichen-forming basidiomycete *Dictyonema glabratum*. *Fungal Genet Biol* 35: 35-247.

Trembley, M. L. , Ringli, C. , and Honegger, R. (2002b) Morphological and molecular analysis of early stages in the resynthesis of the lichen *Baeomyces rufus*. *Mycol Res* 106: 106-768.

Trench, R. K. (1993) Microalgal-invertebrate symbioses: a review. *Endocytobiosis Cell Res*. 9: 9-135.

Trench, R. K. (1997) Diversity of symbiotic dinoflagellates and the evolution of microalgal invertebrate symbiosis. *Proc Int Coral Reef Symp* 8th Panama 2: 2-1275.

Tschermak-Woess, E. (1988) The algal partner. In: Galun, M. (Ed.) *CRC Handbook of Lichenology*, Vol. I. CRC Press, Boca Raton, Florida, FL, USA. pp. 39-92.

Turk, K. A. , Rees, A. P. , Zehr, J. P. , Pereiro, N. , Shelley, R. , Lohan, M. , Malcolm, E. , Woodward, E. M. S. , and Gilbert, J. (2011) Nitrogen fixation and nitrogenase (nifH) expression in tropical waters of the eastern North Atlantic. *Isme J* 5: 1201-1212. doi:10.1038/ismej.2010.205.

Tumer, N. E. , Robinson, S. J. , and Haselkorn, R. (1983) Different promoters for the *Anabaena* glutamine synthetase gene during growth using molecular or fixed nitrogen. *Nature (London)* 306: 306-337.

Uheda, E. (1986) Isolation of hair cells from *Azolla filiculoides* var. *japonica* leaves. *Plant Cell Physiol* 27: 27-1255.

Uheda, E. , Maejima, K. , and Shiomi, N. (2004) Localization of glutamine synthetase isoforms in hair cells of *Azolla* leaves. *Plant Cell Physiol* 45: 45-1087.

Unson, M. D. , and Faulkner, D. J. (1993) Cyanobacterial symbiont biosynthesis of chlorinated metabolites from *Dysidea herbacea* (Porifera). *Cell Mol Life Sci* 49: 49-349.

Unson, M. D. , Holland, N. D. , and Faulkner, D. J. (1994) A brominated secondary metabolite synthesized by the cyanobacterial symbiont of a marine sponge and accumulation of the crystalline metabolite in the sponge tissue. *Mar Biol* 119: 119-210.

Usher, K. M. , Bergman, B. , and Raven, J. A. (2007) Exploring cyanobacterial mutualisms. *Annu Rev Ecol Evol Sys* 38: 255-273. doi: 10.1146/annurevecolsys38.091206.095641.

Usher, K. M. , Fromont, J. , Sutton, D. C. , and Toze, S. (2004a) The biogeography and phylogeny of unicellular cyanobacterial symbionts in sponges from Australia and the Mediterranean. *Microb Ecol* 48: 48-167.

Usher, K. M. , Kuo, J. , Fromont, J. , Kuo, J. , and Sutton, D. C. (2001) Vertical transmission of cyanobacterial symbionts in the marine sponge *Chondrilla australiensis* (Desmospongiae). *Hydrobiologia* 461: 461-515.

Usher, K. M. , Kuo, J. , Fromont, J. , Toze, S. , and Sutton, D. C. (2006) Comparative morphology of five species of symbiotic and non-symbiotic coccoid cyanobacteria. *Eur J Phycol* 41: 41-179.

Usher, K. M. , Toze, S. , Fromont, J. , Kuo, J. , and Sutton, D. C. (2004b) A new species of cyanobacterial symbiont from the marine sponge *Chondrilla nucula*. *Symbiosis* 36: 36-183.

Vacelet, J. (1975) Etude en microscopie electronique de l'association entre bacteries et spongiaires du genre *Verongia* (Dictyoceratida). *J Microsc Biol Cell* 23: 23-271.

Vacelet, J. , and Donadey, C. (1977) Electron microscope study of the association between some sponges and bacteria. *J Exp Mar Ecol* 30: 30-301.

Vacelet, J. , Boury-Esnault, N. , Fiala-Medioni, A. , and Fisher, C. R. (1995) A methanotrophic carnivorous sponge. *Nature (London)* 377: 296.

Vagnoli, L. , Margheri, M. C. , Allotta, G. , and Materassi, R. (1992) Morphological and physiological properties of symbiotic cyanobacteria. *New Phytol* 120: 120-243.

Van Pelt, R. (2001) Forest giants of the Pacific Coast. Global Forest Society and University of Washington Press, Seattle, WA, USA.

Venrick, E. (1974) The distribution and significance of *Richelia intracellularis* Schmidt in the North Pacific central gyre. *Limnol Oceanogr* 19: 19-437.

Villareal, J. C. A. , and Renzaglia, S. (2006) Structure and development of *Nostoc* strands in *Leiosporoceros dussii* (Anthocerotophyta): A novel symbiosis in land plants. *Am J Bot* 93: 93-693.

Villareal, T. A. (1987) Evaluation of nitrogen fixation in the diatom genus *Rhizosolenia* Ehr. in the absence of its cyanobacterial symbiont *Richelia intracellularis* Schmidt. *J Plankton Res* 9: 9-965.

Villareal, T. A. (1989) Division cycles in the nitrogen-fixing *Rhizosolenia* (Bacillariophyceae) *Richelia* (Nostocaceae) symbiosis. *Br Phycol J* 24: 24-357.

Villareal, T. A. (1990) Laboratory culture and preliminary characterization of the nitrogen-fixing *Rhizosolenia*-*Richelia* symbiosis. *Mar Ecol* 11: 11-117.

Villareal, T. A. (1991) Nitrogen-fixation by the cyanobacterial symbiont of the diatom genus *Hemiaulus*. *Mar Ecol Prog Ser* 76: 76-201.

Villareal, T. A. (1992) Marine nitrogen-fixing diatom-cyanobacteria symbioses. In: Carpenter, E. J. , Capone, D. G. , and Rueter, J. G. (Eds.) *Marine Pelagic Cyanobacteria: Trichodesmium and Other Diazotrophs*. Kluwer Academic Publishers, Amsterdam, The Netherlands. pp. 163-175.

Villareal, T. A. (1994) Widespread occurrence of the *Hemiaulus*-cyanobacteria symbiosis in the southwest North Atlantic Ocean. *Bull Mar Sci* 54: 54-61.

Villareal, T. A. , Adornato, L. , Wilson, C. , and Schoenbaechler, C. A. (2011) Summer blooms of diatom-diazotroph assemblages and surface chlorophyll in the North Pacific gyre: A disconnect. *J Geophys Res* 116: doi:10.1029/2010JC006268, 2011

Villareal, T. A. , Altabet, M. A. , and Culver-Rymza, K. (1993) Nitrogen transport by vertically migrating diatom mats in the North Pacific Ocean. *Nature (London)* 363: 363-709.

Vitikainen, O. (1994) Taxonomic revision of *Peltigera* (lichenized Ascomycotina) in Europe. *Acta Bot Fennica* 152: 152-161.

Vivas, M. , Sacrist n, M. , Legaz, M. E. , and Vicente, C. (2010) The cell recognition model in chlorolichens involving a fungal lectin binding to an algal ligand can be extended to cyanolichens. *Plant Biol* 12: 12-615.

Von Neumann, D. , Ackerman, M. , and Jacob, F. (1970) Cited from Silvester, W. B. and McNamara, P. J. (1976).

Wagner, G. M. (1987) *Azolla*: A review of its biology and utilization. *Bot Rev* 63: 1-26.

Wang, C. M. , Ekman, M. , and Bergman, B. , (2004) Expression of cyanobacterial genes involved in heterocyst differentiation and dinitrogen fixation along a plant symbiosis development profile. *Mol Plant-Microbe Interactions* 17: 17-438.

Watanabe, K. (1924) Studien  ber die Korallolide von *Cycas revolute*. *Botanical Magazine* 38: 38-165.

Webb, V. L. , and Mass, E. W. (2002) Sequence analysis of 16S rRNA gene of cyanobacteria associated with the marine sponge *Mycale* (*Carmia*) *hentscheli*. *FEMS Microbiol Lett* 207: 207-243.

Webster, N. S. , Wilson, K. J. , Blackall, L. L. , and Hill, R. T. (2001) Phylogenetic diversity of bacteria associated with the marine sponge *Rhopaloeides odorabile*. *Appl Environ Microbiol* 67: 67-434.

Weisburg, W. G. , Barns, S. M. , Pelletier, D. A. , and Lane, D. J. (1991) 16S ribosomal DNA amplification for phylogenetic study. *J Bacteriol* 173: 173-697.

Wessels, J. G. H. (1994) Developmental regulation of fungal cell wall formation. *Annu Rev Phytopathol* 32: 32-413.

Wessels, J. G. H. (1997) Hydrophobins: Proteins that change the nature of the fungal surface. *Adv Microb Physiol* 38: 38-41.

Wessels, J. G. H. (2000) Hydrophobins, unique fungal proteins. *Mycologist* 14: 14-153.

Wessels, J. G. H. , de Vries, O. M. H. ,  sgeirsd ttir, S. A. , and Schuren, F. H. J. (1991) Hydrophobin genes involved in formation of aerial hyphae and fruit bodies in *Schizophyllum commune*. *Plant Cell* 3: 3-793.

West, N. J. , and Adams, D. G. (1997) Phenotypic and genotypic comparison of symbiotic and free-living cyanobacteria from a single field site. *Appl Environ Microbiol* 63: 63-4479.

White, A. E. , Prah, F. G. , Letelier, R. M. , and Popp, B. N. (2007a) Summer surface waters in the Gulf of California: Prime habitat for biological N₂ fixation, *Global Biogeochem Cycles* 21: GB2017, doi:10.1029/2006GB002779

White, A. E. , Spitz, Y. H. , and Letelier, R. M. (2007b) What factors are driving summer phytoplankton blooms in the North Pacific subtropical gyre? *J Geophys Res* 112: C12006. doi:10.1029/2007JC004129

White, F. J. , and James, P. W. (1988) Studies on the genus *Nephroma* II. The Southern temperate species. *Lichenologist* 20: 20-103.

Whiteford, J. R. , and Spanu, P. D. (2002) Hydrophobins and the interactions between fungi and plants. *Mol Plant Pathol* 3: 3-391.

Wilkinson, C. R. (1983) Net primary productivity in coral reef sponges. *Science* 219: 219-410.

Wilkinson, C. R. (1992) Symbiotic interactions between marine sponges and algae. In: Reisser, W. (Ed.) *Algae and Symbioses*. Bioprocess, Bristol, England, UK. pp. 112-151.

Wilkinson, C. R. , and Fay, P. (1979) Nitrogen fixation in coral reef sponges with symbiotic cyanobacteria. *Nature (London)* 279: 279-527.

Wilkinson, C. R. , and Vacelet, J. (1979) Transplantation of marine sponges to different conditions of light and current. *J Exp Mar Biol Ecol* 37: 37-91.

Wilson, C. , Villareal, T. A. , Maximenko, N. , Bograd, S. J. , Montoya, J. P. , and Schoenbaechler, C. A. (2008) Biological and physical forcings of late summer chlorophyll blooms at 30 N in the oligotrophic Pacific. *J Mar Syst* 69: 164-176. doi:10.1016/j.jmarsys.2005.09.018

- Winter, G. (1935) Über die Assimilation des Luftstickstoffs durch endophytische Blaualgen. *Beitr Biol Pflanzen* 23: 23-295.
- Wirtz, N. , Lumbsch, H. T. , Green, T. G. A. , Turk, R. , Pintado, A. , Sancho, L. , and Schroeter, B. (2003) Lichen fungi have low cyanobiont selectivity in maritime Antarctica. *New Phytol* 160: 160-177.
- Wittman, W. , Bergersen, F. J. , and Kennedy, G. S. (1965) The coralloid roots of *Macrozamia communis* L.Johnson. *Aus J Biol Sci* 18: 18-1129.
- Wolf, E. (2003) Partnererkennung und Inkorporation bei der Pilz-Endocyanose *Geosiphon pyriformis*. Technische Universität Darmstadt, Hessische Landes-und Hochschulbibliothek.
- Wolk, C. P. (2000) Heterocyst formation in *Anabaena*. In: Brun, Y. V. , and Shimkers, L. J. (Eds.) *Prokaryotic Development*. American Society for Microbiology, Washington, D. C. USA. pp. 83-104.
- Woodson, S. A. , and Cech, T. R. (1989) Reverse splicing of the Tetrahymena group I introns: Implication for the directionality of splicing and for intron transposition. *Cell* 57: 57-335.
- Wong, F. C. Y. , and Meeks, J. C. (2001) The hetF gene product is essential to heterocyst differentiation and affects HetR function in the cyanobacterium *Nostoc punctiforme*. *J Bacteriol* 183: 183-2654.
- Wong, F. C. Y. , and Meeks, J. C. (2002) Establishment of a functional symbiosis between the cyanobacterium *Nostoc punctiforme* and the bryophyte *Anthoceros punctatus* requires genes involved in nitrogen control and initiation of heterocyst differentiation. *Microbiology* 148: 148-315.
- Wösten, H. A. B. (2001) Hydrophobins: Multipurpose proteins. *Annu Rev Microbiol* 55: 55-625.
- Wösten, H. A. B. , Ásgeirsdóttir, S. A. , Krook, J. H. , Drenth, J. H. H. , and Wessels, J. G. H. (1994) The SC3 hydrophobin selfassembles at the surface of aerial hyphae as a protein membrane constituting the hydrophobic rodlet layer. *Eur J Cell Biol* 63: 63-122.
- Wösten, H. A. B. , De Vries, O. M. H. , and Wessels, J. G. H. (1993) Interfacial self-assembly of a fungal hydrophobic rodlet layer. *Plant Cell* 5: 15-1567.
- Wösten, H. A. B. , Ruardy, T. G. , van der Mei, H. C. , Busscher, H. J. , and Wessels, J. G. H. (1995) Interfacial self-assembly of a *Schizophyllum commune* hydrophobin into an insoluble amphipathic membrane depends on surface hydrophobicity. *Colloids Surf* 5: 5-189.
- Wösten, H. A. B. , Schuren, F. H. J. , and Wessels, J. G. H. (1994) Interfacial self-assembly of a hydrophobin into an amphipathic membrane mediates fungal attachment to hydrophobic surfaces. *Embo J* 13: 13-5848.
- Wynne, M. J. (1969) Life history and systematic studies of Pacific North American Phaeophyceae (brown algae). *Univ Calif Publi Bot* 50: 50-51.
- Wynn-Williams, D. D. , (2000) Cyanobacteria in the deserts-life at the limit?. In: Whitton, B.A. , Potts, M. (Eds.), *The Ecology of Cyanobacteria*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 341-366.
- Xie, Z.-P. , Stachelibn, C. , Vierheilg, H. , Wiemken, A. , Jabbouri, S. , Broughton, W. J. , Vögeli-Lange, R. , and Boller, T. (1995) Rhizobial nodulation factors stimulate mycorrhizal colonization of nodulating and nonnodulating soybeans. *Plant Physiol* 108: 108-1519.
- Xu, M. Q. , Kathe, S. D. , Goodrichblair, H. , Nierzwicki-Bauer, S. A. , and Shub, D. A. (1990) Bacterial origin of a chloroplast intron-conserved self-splicing group I introns in cyanobacteria. *Science* 250: 250-1566.
- Yoshimura, I. , Kurokawa, T. , and Kinoshita, Y. (1993) Development of lichen thalli in vitro. *Bryologist* 96: 96-412.
- Yoshimura, I. , Kurokawa, T. , Yamamoto, Y. , and Kinoshita, Y. (1994) In vitro development of the lichen thallus of some species of *Peltigera*. *Cryptogamic Botany* 4: 4-314.
- Zackrisson, O. , DeLuca, T. H. , Nilsson, M.-C. , Sellstedt, A. , and Berglund, L. (2004) Nitrogen fixation increases with successional age in boreal forests. *Ecology* 85: 85-3327.
- Zeev, E. B. , Yogev, T. , Man-Ahronovich, D. , Kress, N. , Hernt, B. , Bêjá, O. , and Berman-Frank, I. (2008) Seasonal dynamics of the endosymbiotic nitrogen-fixing cyanobacterium *Richelia intracellularis* in the eastern Mediterranean Sea. *Isme J* 2: 2-911.
- Zehr, J. P. , and Kudela, R. M. (2011) Nitrogen cycle of the open ocean: From genes to ecosystems. *Annu Rev Mar Sci* 3: 3-197.
- Zhang, L. , Villalon, D. , Sun, Y. , Kazmierczak, P. , and Van Alfen, N. K. (1994) Virus-associated down-regulation of the gene encoding cryparin, an abundant cell-surface protein from the chestnut blight fungus, *Cryphonectria parasitica*. *Gene* 139: 139-159.
- Zheng, W. , China, P. R. , Song, T. , Bao, X. , Bergman, B. , and Rasmussen, U. (2002) High cyanobacterial diversity in coralloid roots of cycads revealed by PCR fingerprinting. *FEMS Microbiol Ecol* 40: 40-215.
- Zhu, C. (1982) Fine structure of blue-green algae and the cells lined along the endophyte cavity in the coralloid roots of *Cycas*. *Acta Bot Sinica* 24: 109-114 (in Chinese).
- Ziegler, R. (1992) Komplex-thallöse, fossil Organismen mit blattflechtenartigen Bau aus dem mittleren Keuper (Trias, Karn) Unterfrankens. In: Kovar-Eder (Ed.) *Palaeovegetational development in Europe and regions relevant to its palaeofloristic evolution*. Museum of Natural History, Vienna. pp. 341-349.
- Zimmerman, R. A. , and Dahlberg, A. E. (Eds.) (1996) *Ribosomal RNA: Structure, Evolution, Processing and Function in Protein Biosynthesis*. CRC Press, Boca Raton, Florida, FL, USA.
- Zimmerman, W. J. , and Bergman, B. (1990) The *Gunnera* symbiosis: DNA restriction fragment length polymorphism and protein comparisons of *Nostoc* symbionts. *Microb Ecol* 19: 19-291.
- Zimmerman, W. J. , Rosen, B. H. , and Lumpkin, T. A. (1989) Enzymatic lectin and morphological characterization and classification of presumptive cyanobionts from *Azolla* Lam. *New Phytol* 113: 113-497.
- Zimmerman, W. J. , Watanabe, I. , Ventura, T. , Payawal, P. , and Lumpkin, T. A. (1991) Aspects of the genetic and botanical status of neotropical *Azolla* species. *New Phytol* 119: 119-561.
- Zoller, S. , Lutizoni, F. , and Scheidegger, C. (1999) Genetic variation within and among populations of the threatened lichen *Lobaria pulmonaria*. Switzerland and implications for its conservation. *Mol Ecol* 8: 2049-2059.

Cyanophages

- Ackermann, H.-W. (2007) 5500 Phages examined in the electron microscope. *Arch Virol* 152: 277-343.
- Ackermann, H.-W. (2011) Bacteriophage taxonomy. *Microbiology Australia*. May 2011. pp. 90-94.
- Ackermann, H.-W. and Haldal, M. (2010) Basic electron microscopy of aquatic viruses. Chapter 18. In: *Manual of Aquatic Viral Ecology*. The American Society of Limnology and Oceanography. pp. 132-192.
- Ackerman, H.-W. , Audurier, A. , Berthiaume, L. , Jones, L. A. , Mayo, J. A. , and Vidaver, A. K. (1978) Guidelines for bacteriophage characterization. *Adv Virus Res* 23: 1-24.
- Adolph, K. W. , and Haselkorn, R. H. (1971) Isolation and characterization of a virus infecting the blue-green alga *Nostoc muscorum*. *Virology* 46: 200-208.
- Adolph, K. W. , and Haselkorn, R. H. (1972) Photosynthesis and the development of blue-green algal virus N-1. *Virology* 47: 370-374.
- Adolph, K. W. , and Haselkorn, R. (1973a) Isolation and characterization of a virus infecting a blue-green alga of the genus *Synechococcus*. *Virology* 54: 230-236.
- Adolph, K. W. , and Haselkorn, R. (1973b) Blue-green algal virus N-1: Physical properties and disassembly into structural parts. *Virology* 53: 427-440.
- Al-Musavi, R. A. (1977) Effect of photosynthesis and respiration on growth of cyanophages of *Anabaena variabilis*. *Mikrobiologiya* 46: 725-729.
- Alperovitch-Lavy, A. , Sharon, I. , Rohwer, F. , Aro, E.-M. , Glaser, F. , Milo, R. , Nelson, N. , and Béjà, O. (2011) Reconstructing a puzzle: Existence of cyanophages containing both photosystem-I and photosystem-II gene suites inferred from oceanic metagenomic datasets. *Environ Microbiol* 13: 24-32. doi:<https://doi.org/10.1111/j.1462-2920.2010.02304.x>
- Amla, D. V. (1978) Stability, adsorption and growth characteristics of cyanophage AS-1. In: S. P. Singh , Tiwari, D. N. , Kashyap A. K. , and Yadav, P. K. . (Eds.) *Advances in Cyanophyte Research*. Banaras Hindu University, Varanasi. pp. 131-139.
- Amla, D. V. (1979) Characteristics of pigment mutants of *Anacystis nidulans*: UV sensitivity and multiplication of cyanophage AS-1. *Biochem Physiol Pflanzen* 174: 678-684.
- Amla, D.V. (1981) Isolation of characteristics of minute plaque forming mutant of cyanophage AS-1. *Biochem Physiol Pflanzen* 176: 83-89.
- Amla, D. V. , and Saxena, P. N. (1983) Metabolic aspects of cyanophage AS-1 replication and reproduction in cyanobacterium *Anacystis nidulans*. *Biochem Physiol Pflanzen* 178: 225-236.
- Amla, D. V. , Rowell, P. , and Stewart, W. D. P. (1987) Metabolic changes associated with cyanophage N-1 infection of cyanobacterium *Nostoc muscorum*. *Arch Microbiol* 148: 321-327.
- Angly, F. , Felts, B. , Breitbart, M. , Salamon, P. , Edwards, R. , Carlson, C. , Chan, A. M. , Haynes, M. , Kelley, S. , Liu, H. , Mahaffy, J. M. , Mueller, J. E. , Nulton, J. , Olson, R. , Parsons, R. , Rayhawk, S. , Suttle, C. A. , and Rohwer, F. (2006) The marine viromes of four oceanic regions. *PLoS Biol* 4: 2121-2131.
- Bagchi, S. N. , Kaloya, P. , and Bisen, P. S. (1987) Effect of cyanophage N-1 infection on the synthesis and stability of *Nostoc muscorum* nitrate reductase. *Curr Microbiol* 15: 61-65.
- Bailey, S. , Clokie, M. R. J. , Millard, A. , and Mann, N. H. (2004) Cyanophage infection and photoinhibition in marine cyanobacteria. *Res Microbiol* 155: 720-725.
- Baker, A. C. , Goddard, V. J. , Davy, J. , Schroeder, D. C. , Adams, D. G. , and Wilson, W. H. (2006) Identification of a diagnostic marker to detect freshwater cyanophages of filamentous cyanobacteria. *Appl Environ Microbiol* 72: 5713-5719.
- Bancroft, I. , and Smith, R. J. (1988a) The isolation of genomic DNA from cyanophages infecting *Nostoc* and *Anabaena* species of cyanobacteria. *New Phytol* 110: 233-239.
- Bancroft, I. , and Smith, R. J. (1988b) Analysis of restriction endonuclease sites in cyanophages infecting the heterocystous cyanobacteria. *J Gen Virol* 69: 739-743.
- Bancroft, I. , and Smith, R. J. (1989) Restriction mapping of genomic DNA from five cyanophages infecting the heterocystous cyanobacteria *Nostoc* and *Anabaena*. *New Phytol* 113: 161-166.
- Barnet, Y. M. , Daft, M. J. , and Stewart, W. D. P. (1981) Cyanobacteria-cyanophage interactions in continuous culture. *J Appl Bacteriol* 51: 541-552.
- Barnet, Y. M. , Daft, M. J. , and Stewart, W. D. P. (1984) The effect of suspended particulate material on cyanobacteria-cyanophage interactions in liquid culture. *J Appl Microbiol* 56: 109-116.
- Barns, S. M. , Fundyga, R. E. , Jeffries, M. W. , and Pace, N. R. (1994) Remarkable archaeal diversity detected in a Yellowstone National Park hot spring environment. *Proc Natl Acad Sci USA* 91: 1609-1613.
- Bench, S. R. , Hanson, T. E. , Williamson, K. E. , Ghosh, D. , Radosovich, M. , Wang, K. , and Wommack, K. E. (2007) Metagenomic characterization of Chesapeake Bay viroplankton. *Appl Environ Microbiol* 73: 7629-7641.
- Benson, R. , and Martin, E. (1981) Effect of photosynthetic inhibitors and light dark regimes on the replication of cyanophage SM-2. *Arch Microbiol* 129: 165-167.
- Bergh, O. , Børsheim, K. Y. , Bratbak, G. , and Haldal, M. (1989) High abundance of viruses found in aquatic environments. *Nature (London)* 340: 467-468.
- Bettarel, Y. , Sime-Ngando, T. , Amblard, C. , and Laveran, H. (2000) A comparison of methods for counting viruses in aquatic systems. *Appl Environ Microbiol* 66: 2283-2289.
- Bisen, P. S. , Audholia, S. , and Bhatnagar, A. K. (1985) Mutation to resistance for virus AS-1 in the cyanobacterium *Anacystis nidulans*. *Microbios Lett* 29: 7-13.
- Bisen, P. S. , Audholia, S. , Bhatnagar, A. K. , and Bagchi, S. N. (1986b) Evidence for lysogeny and viral resistance in the cyanobacterium *Phormidium uncinatum*. *FEMS Microbiol Lett* 52: 225-228.
- Bisen, P. S. , Audholia, S. , Shukla, H. O. , Gupta, A. , and Singh, D. P. (1988) Evidence for photosynthetic independence of viral multiplication of cyanophage LPP-1 infected cyanobacterium *Phormidium uncinatum*. *FEMS Microbiol Lett* 52: 225-228.
- Bisen, P. S. , Bagchi, S. N. , and Audholia, S. (1986a) Nitrate reductase activity of a cyanobacterium *Phormidium uncinatum* after cyanophage LPP-1 infection. *FEMS Microbiol Lett* 33: 69-72.
- Blashka, K. H. , Hwang-Lee, L. , Cohn, G. , Blamire, J. , and McGowan, R. E. (1982) Altered metabolite incorporation into cyanobacterium *Anacystis nidulans* as a result of cyanophage AS-1 infection. *Microbios* 34: 141-152.
- Blashka, K. H. , Hwang-Lee, L. , McGowan, R. E. , and Blamire, J. (1983) DNA metabolism during infection of *Anacystis nidulans* by cyanophage AS-1: 3-alternative precursors and host/phage systems for PIL-DNA. *Microbios* 36: 93-100.

Bobrovnik, S. A. , Mendzhul, M. I. , and Lysenko, T. G. (1978) Kinetics mechanism and thermodynamics of cyanophage A-1 adsorption on the cells of algae-host. *Biofizika* 23: 489-493.

Bograh, A. , Gingras, Y. , Tajmir-Riahi, H. A. , and Carpentier, R. (1997) The effects of spermine and spermidine on the structure of photosystem II proteins in relation to inhibition of electron transport. *FEBS Lett* 402: 41-44.

Bohannon, B. J. M. , and Lanski, R. E. (2000) Linking genetic change to community evolution: Insights from studies of bacteria and bacteriophage. *Ecol Lett* 3: 362-377.

Booth, S. J. (1975) Isolation, identification and partial characterization of cyanophage LPP-2N. Ph. D. Thesis, University of Nebraska, NE, USA.

Borbely, G. , Kaki, C. , Gulyas, A. , and Farkas, G. L. (1980) Bacteriophage infection interferes with guanosine 3'-diphosphate- 5'-diphosphate accumulation induced by energy and nitrogen starvation in the cyanobacterium *Anacystis nidulans*. *J Bacteriol* 144: 859-864.

Børstheim, K. Y. , Bratbak, G. , and Heldal, M. (1990) Enumeration and biomass estimation of planktonic bacteria and viuses by transmission electron microscopy. *Appl Environ Microbiol* 56: 352-356.

Bradley, D. E. (1967) Ultrastructure of bacteriophage and bacteriocins. *Bacteriol Rev* 31: 230-314.

Braeken, K. , Moris, M. , Daniels, R. , Vanderleyden, J. , and Michiels, J. (2006) New horizons for (p)ppGpp in bacterial and plant physiology. *Trends Microbiol* 14: 45-54.

Bragg, J. G. , and Chisholm, S. W. (2008) Modeling the fitness consequences of a cyanophage encoded photosynthetic gene. *PLoS ONE* 3: e3550. doi:https://doi.org/10.1371/journal.pone.0003550

Bratbak, G. , and Heldal, M. (1993) Total count of viruses in aquatic environments. In: Kemp, P. F. , Sherr, B. F. , and Cole, J. J. . (Eds.) *Current Methods in Aquatic Microbial Ecology*. Lewis Publishers, London, UK. pp. 135-138.

Bratbak, G. , Heldal, M. , Norland, S. , and Thingstad, T. F. (1990) Viruses as partners in spring bloom microbial trophodynamics. *Appl Environ Microbiol* 56: 1400-1405.

Bratbak, G. , Heldal, M. , Thingstad, T. F. , Rieman, B. , and Haslund, O. H. (1992) Incorporation of viruses into the budget of microbial C-transfer. A first approach. *Mar Ecol Prog Ser* 83: 273-280.

Breitbart, M. (2012) Marine viruses: Truth or dare. *Annu Rev Mar Sci* 4: 425-448. doi:https://doi.org/10.1146/annurev-marine120709-142805

Breitbart, M. , and Rohwer, F. (2005) Here a virus, there a virus, everywhere the same virus? *Trends Microbiol* 13: 278-284.

Breitbart, M. , Miyake, J. H. , and Rohwer, F. (2004) Global distribution of identical phage-encoded DNA sequences. *FEMS Microbiol Lett* 236: 244-256.

Breitbart, M. , Salamon, P. , Andresen, B. , Mahaffy, J. M. , Segall, A. M. , Mead, D. , Azam, F. , and Rohwer, F. (2002) Genomic analysis of uncultured marine viral communities. *Proc Natl Acad Sci USA* 99: 14250-14255.

Breitbart, M. , Thompson, L. R. , Suttle, C. S. , and Sullivan, M. B. (2007) Exploring the vast diversity of marine viruses. *Oceanography* 20: 135-139.

Breitbart, M. , Wegley, L. , Leeds, S. , Schoenfeld, T. , and Rohwer, F. (2004) Phage community dynamics in hot springs. *Appl Environ Microbiol* 70: 1633-1640.

Brown, R. M., Jr. , Smith, K. M. , and Walne, P. L. (1966) Replication cycle of the blue-green algal virus LPP-1. *Nature (London)* 212: 729-730.

Brussaard, C. P. D. (2004) Optimization of procedures for counting viruses by flow cytometry. *Appl Environ Microbiol* 70: 1506-1513.

Brussaard, C. P. D. , Kuipers, B. , and Veldhuis, M. J. W. (2005) A mesocosm study of *Phaeocystis globosa* population dynamics. I. Regulatory role of viruses in bloom control. *Harmful Algae* 4: 859-874.

Brussaard, C. P. D. , Riegman, R. , Noordeloos, A. A. M. , Codee, G. C. , Witte, H. , Kop, A. J. , Nieuwland, G. , van Duyl, F. C. , and Bak, R. P. M. (1995) Effects of grazing sedimentation and phytoplankton cell lysis on the structure of a coastal pelagic food web. *Mar Ecol Prog Ser* 123: 259-271.

Brussaard, C. P. D. , Timmermans, K. R. , Uitz, J. , and Veldhuis, M. J. W. (2008) Virioplankton dynamics and virally induced phytoplankton lysis versus microzooplankton grazing southeast of the Kerguelen (Southern Ocean). *Deep-Sea Res II* 55: 752-765.

Bryan, M. J. , Burroughs, N. J. , Spence, E. M. , Clokie, M. R. J. , Mann, N. H. , and Bryan, S. J. (2008) Evidence for the intense exchange of MazG in marine cyanophages by horizontal gene transfer. *PLoS ONE* 3: e2048. doi:https://doi.org/10.1371/journal.pone.0002048

Buckling, A. , and Rainey, P. B. (2002) Antagonistic co-evolution between a bacterium and a bacteriophage. *Proc R Soc B London* 269: 1385-1391.

Budinoff, C. R. , Loar, S. N. , LeClerc, G. R. , Wilhelm, S. W. , and Buchan, A. (2011) A protocol for the enumeration of aquatic viruses by epifluorescence microscopy using AnodiscTM membranes. *BMC Microbiol* 11: 168. doi:https://doi.org/10.1186/1471-2-180-11-168.

Campbell, L. , Nolla, H. A. , and Vaulot, D. (1994) The importance of *Prochlorococcus* to community structure in the central Pacific Ocean. *Limnol Oceanogr* 39: 954-961.

Cannon, R. E. , and Shane, M. S. (1972) The effect of antibiotic stress on protein synthesis in the establishment of lysogeny of *Plectonema boryanum*. *Virology* 49: 130-133.

Cannon, R. E. , Shane, M. S. , and Bush, V. N. (1971) Lysogeny of a blue-green alga, *Plectonema boryanum*. *Virology* 45: 149-153.

Cannon, R. E. , Shane, M. S. , and Whitaker, J. M. (1976) Interaction of *Plectonema boryanum* (Cyanophyceae) and the LPP-cyanophages in continuous culture. *J Phycol* 12: 418-421.

Charlson, R. J. , Lovelock, J. E. , Andreae, M. O. , and Warren, S. G. (1987) Oceanic phytoplankton, atmospheric sulphur, cloud albedo and climate. *Nature (London)* 326: 655-661.

Chen, F. , and Lu, J. (2002) Genomic sequence and evolution of marine cyanophage P60: A new insight on lytic and lysogenic phages. *Appl Environ Microbiol* 68: 2589-2594.

Chen, F. , Lu, J.-R. , Binder, B. J. , Liu, Y.-C. , and Hodson, R. E. (2001) Application of digital image analysis and flow cytometry to enumerate marine viruses stained with SBYR Gold. *Appl Environ Microbiol* 67: 539-545.

Chen, F. , Wang, K. , Kan, J. , Bachoon, D. S. , Lu, J. , Lau, S. , and Campbell, L. (2004) Phylogenetic diversity of *Synechococcus* in the Chesapeake Bay revealed by ribulose-1,5-biphosphate carboxylase-oxygenase (RuBisCO) large subunit gene (rbcL) sequences. *Aquat Microb Ecol* 136: 153-164.

Chénard, C. , and Suttle, C. A. (2008) Phylogenetic diversity of sequences of cyanophage photosynthetic gene psbA in marine and freshwaters. *Appl Environ Microbiol* 74: 5317-5324.

Chisholm, S. W. (1992) Phytoplankton size. In: Falkowski, P. G. , and Woodhead, A. D. . (Eds.) *Primary Productivity and Biogeochemical Cycles in the Sea*. Plenum Press, New York, NY, USA. pp. 213-237.

Clokier, M. R. J. , and Mann, N. H. (2006) Marine cyanophages and light. *Environ Microbiol* 8: 2074-2082.

Clokier, M. R. J. , Millard, A. D. , Mehta, J. Y. , and Mann, N. H. (2006) Virus isolation studies suggest short-term variations in abundance in natural cyanophage populations of the Indian Ocean. *J Mar Biol Ass UK* 86: 499-505.

Comeau, A. M. , Arbiol, C. , and Krisch, H. M. (2010) Gene network visualization and quantitative synteny analysis of more than 300 marine T4-like phage scaffolds from the GOS metagenome. *Mol Biol Evol* 27: 1935-1944. doi:<https://doi.org/10.1093/molbev/msq076>

Cottrell, M. T. , and Suttle, C. A. (1991) Wide-spread occurrence and clonal variation in viruses which cause lysis of a cosmopolitan, eukaryotic marine plankter, *Micromonas pusilla*. *Mar Ecol Prog Ser* 78: 1-9.

Cseke, C. A. , and Farkas, G. L. (1979) Effect of light on the attachment of cyanophage AS-1 to *Anacystis nidulans*. *J Bacteriol* 137: 667-669.

Cseke, C. A. , Balogh, A. , and Farkas, G. L. (1981) Redox modulation of glucose-6-phosphate dehydrogenase in *Anacystis nidulans* and its 'uncoupling' by phage infection. *FEBS Lett* 126: 85-88.

Daft, M. J. , Begg, J. , and Stewart, W. D. P. (1970) A virus of blue-green algae from freshwater habitats in Scotland. *New Phytol* 69: 1029-1038.

Dammeyer, T. , Bagby, S. C. , Sullivan, M. B. , Chisholm, S. W. , and Frankenberg-Dinkel, N. (2008) Efficient phage-mediated pigment biosynthesis in oceanic cyanobacteria. *Curr Biol* 18: 442-448.

Danovaro, R. , and Serresi, M. (2000) Viral density and Virus-to-bacterium ratio in deep-sea sediments of the Eastern Mediterranean. *Appl Environ Microbiol* 66: 1857-1861.

Danovaro, R. , Corinaldesi, C. , Dell'Anno, A. , Fuhrman, J. A. , Middelburg, J. J. , Noble, R. T. , and Suttle, C. A. (2011) Marine viruses and global climate change. *FEMS Microbiol Rev* 35: 993-1034.

Danovaro, R. , Corinaldesi, C. , Filippini, M. , Fischer, U. R. , Gessner, M. O. , Jacquet, S. , Magagnini, M. , and Velimirov, B. (2008) Viriobenthos in freshwater and marine sediments. *Freshwater Biol* 53: 1186-1213.

Danovaro, R. , Dell'Anno, A. , Trucco, A. , Serresi, M. , and Vanucci, S. (2001) Determination of virus abundance in marine sediments. *Appl Environ Microbiol* 67: 1384-1387.

DeCorte, D. , Sintes, E. , Winter, C. , Yokokawa, T. , Reinthaler, T. , and Herndl, G. J. (2010) Links between viral and prokaryotic communities throughout the water column in the (sub)tropical Atlantic Ocean. *Isme J* 4: 1431-1442. doi:<https://doi.org/10.1038/ismej.2010.65>

d'Herelle, F. (1917) Sur un microbe invisible antagoniste des bacillus dysentériques. *C.R Hebd Seances Acad Sci D* 165: 373-375.

DeLong, E. F. , Preston, C. M. , Mincer, T. , Rich, V. , Hallam, S. J. , Frigaard, N.-U. , Martinez, A. , Sullivan, M. B. , Edwards, R. , Brito, B. R. , Chisholm, S. W. , and Karl, D. M. (2006) Community genomics among stratified microbial assemblages in the Ocean's interior. *Science* 311: 496-503.

Desjardins, P. R. , and Olson, O. B. (1983) Viral control of nuisance cyanobacteria. *California Water Resources Contribution No.* 185. pp. 1-35.

Desplats, C. , Dez, C. , Tétart, F. , Eleaume, H. , and Krisch, H. M. (2002) Snapshot of the genome of the pseudo-T-even bacteriophage RB49. *J Bacteriol* 184: 2789-2804.

Diener, T. O. (1963) Physiology of virus-infected plants. *Annu Rev Phytopathol* 1: 197-218.

Dorigo, U. , Jacquet, S. , and Humbert, J. F. (2004) Cyanophage diversity, inferred from g20 gene analyses, in the largest natural lake in France, Lake Bourget. *Appl Environ Microbiol* 70: 1017-1022.

Drake, L. A. , Doblin, M. A. , and Dobbs, F. C. (2007) Potential microbial bioinvasions via ship's ballast water, sediment and biofilm. *Mar Pollu Bull* 55: 333-341.

Drouet, F. (1963) Ecophenes of *Schizothrix calcicola* (Oscillatoriaceae). *Proc Natl Acad Sci USA* 115: 261-281.

Duhaime, B. M. , Kottmann, R. , Field, D. , and Glöckner, F. O. (2011) Enriching public descriptions of marine phages using Genomic Standards Consortium MIGS standard. *Stand Genomic Sci* 4: 1 doi:<https://doi.org/10.4056/signs.621069>

Dyall-Smith, M. , Tang, S. , and Bath, C. (2003) Haloarchaeal viruses: How diverse are they? *Res Microbiol* 154: 309-313.

Eden, P. A. , Schmidt, T. M. , Blakemore, R. P. , and Pace, N. R. (1991) Phylogenetic analysis of *Aquaspirillum magnetotacticum* using polymerase chain reaction-amplified 16S rRNA-specific DNA. *Int J Syst Bacteriol* 41: 324-325.

Edwards, R. A. , and Rohwer, F. (2005) Viral metagenomics. *Nat Rev Microbiol* 3: 504-510. www.nature.com/reviews/micro.

Enav, H. , Bèjà, O. , and Mandel-Gutfreund, Y. (2012) Cyanophage tRNAs may have a role in cross-infectivity of oceanic *Prochlorococcus* and *Synechococcus* hosts. *Isme J* 6: 619-628. doi:<https://doi.org/10.1038/ismej.2011.146>

Fox, J. A. , Booth, S. J. , and Martin, E. L. (1976) Cyanophage SM-2: A blue-green algal virus. *Virology* 73: 557-560.

Franche, C. (1987) Isolation and characterization of a temperate cyanophage for tropical *Anabaena* strain. *Arch Microbiol* 148: 172-177.

Frederickson, C. M. , Short, S. M. , and Suttle, C. A. (2003) The physical environment affects cyanophage communities in British Columbia inlets. *Microb Ecol* 46: 348-357.

Friga, G. M. , Borbely, G. , and Farkas, G. L. (1981) Accumulation of guanosine tetraphosphate (ppGpp) under nitrogen starvation in *Anacystis nidulans*, a cyanobacterium. *Arch Microbiol* 129: 341-343.

Fuhrman, J. A. (1992) Bacterioplankton roles in cycling of organic matter: The microbial food web. In: Falkowski, P. G. , and Woodhead, A. D. . (Eds.) *Primary Productivity and Biogeochemical Cycles in the Sea*. Plenum Press, New York, NY, USA. pp. 361-383.

Fuhrman, J. A. (1999) Marine viruses and their biogeochemical and ecological effects. *Nature (London)* 399: 541-548.

Fuhrman, J. A. , and Noble, R. T. (1995) Viruses and protists cause similar bacterial mortality in coastal seawater. *Limnol Oceanogr* 40: 1236-1242.

Fuhrman, J. A. , and Suttle, C. A. (1993) Viruses in marine planktonic systems. *Oceanography* 6: 51-63.

Fuller, N. J. , Wilson, W. H. , Joint, I. R. , and Mann, N. H. (1998) Occurrence of a sequence in marine cyanophages similar to that of T4 g20 and its application to PCR-based detection and quantification techniques. *Appl Environ Microbiol* 64: 2051-2060.

Galperin, M. Y. , Moroz, O. V. , Wilson, K. S. , and Murzin, A. G. (2006) House cleaning, a part of good housekeeping. *Mol Microbiol* 59: 5-19.

Gan, E. B. , Gui, J. F. , and Zhang, Q.-Y. (2011) A novel cyanophage with cyanobacterial non-bleaching protein A in the genome. *J Virol* 85: 305-314. doi:<https://doi.org/10.1128/JVI.06282-11>

Garza, D. R. , and Suttle, C. A. (1998) The effect of cyanophages on the mortality of *Synechococcus* and selection for UV-resistant viral communities. *Microb Ecol* 36: 281-292.

Ginzberg, D. , Padan, E. , and Shilo, M. (1968) Effect of cyanophage infection on CO₂ photoassimilation in *Plectonema boryanum*. *J Virol* 2: 695-701.

Giovannoni, S. J. , Britschgi, T. B. , Moyer, C. L. , and Field, K. G. (1990) Genetic diversity in Sargasso Sea bacterioplankton. *Nature* (London) 345: 60-63.

Göbler, C. J. , Hutchins, D. A. , Fisher, N. S. , Cosper, E. M. , and Sanudo-Wilhelmy, S. A. (1997) Release and bioavailability of C, N, P, Se and Fe following viral lysis of a marine chrysophyte. *Limnol Oceanogr* 42: 1492-1504.

Goerick, R. , and Repeta, D. J. (1992) The pigments of *Prochlorococcus marinus*: The presence of divinyl chlorophyll a and b in a marine prokaryote. *Limnol Oceanogr* 37: 425-433.

Goldsmith, D. B. , Crosti, G. , Dwivedi, B. , McDaniel, L. D. , Varsani, A. , Suttle, C. A. , Weinbauer, M. G. , Sandaa, R. A. , and Breitbart, M. (2011) Development of *phoH* as a novel signature gene for assessing marine phage diversity. *Appl Environ Microbiol* 77: 7730-7739.

Goldstein, D. A. , Bendet, I. J. , Lauffer, M. A. , and Smith, K. M. (1967) Some biological and physicochemical properties of blue-green algal virus LPP-1. *Virology* 32: 601-613.

Goryushin, V. A. , and Shainskaya, O. A. (1984) Isolation and characterization of a strain of the cyanophage AS-1: AS-1K. *Microbiologiya* 46: 70-75.

Granhall, U. , and Hofsten, A. V. (1969) The ultrastructure of a cyanophage attack on *Anabaena variabilis*. *Physiol Plant* 22: 713-722.

Gromov, B. V. (1983) Cyanophages. *Ann Microbiol (Inst. Pasteur)* 134: 43-59.

Gromov, B. V. , and Koz'yakov, S. Y. (1970) Study of the properties of the interrelationship between populations of the blue- green alga *Plectonema boryanum* Gom, and the cyanophages LPP-1. *Vestn Leningrad Univ Ser Biol* 1: 128-135.

Gross, M. , Marianovsky, I. , and Glaser, G. (2006) MazG-a regulator of programmed cell death in *Escherichia coli*. *Mol Microbiol* 59: 590-601.

Guixa-Boixareu, N. , Calderon-Paz, J. , Heldal, M. , Bratbak, G. , and Pedros-Alio, C. (1996) Viral lysis and bacteriophage as prokaryotic loss factors along a salinity gradient. *Aquat Microb Ecol* 11: 215-227.

Gusev, M. V. , Zhivepistseva, I. V. , Matorin, D. N. , Nikitino, K. A. , and Timofeev, K. N. (1980a) Degradation of *Anacystis nidulans* cells during treatment with cyanophage AS-1. *Vopr Virusol* 3: 330-333.

Gusev, M. V. , Zhivepistseva, I. V. , Matorin, D. N. , Nikitino, K. A. , and Timofeev, K. N. (1980b) Sequence of degradation process in *Anabaena variabilis* photosynthetic apparatus affected by cyanophage A-1L. *Fiziol Rast (Mosc)* 27: 470-476.

Hall, M. J. , Wharam, S. D. , Weston, A. , Cardy, D. L. N. , and Wilson, W. H. (2002) Use of signal-mediated amplification of RNA technology (SMART) to detect marine cyanophage DNA. *BioTechniques* 32: 604-611.

Hambly, E. (2002) Molecular Studies of Marine Cyanophages. Ph.D. Thesis. University of Warwick, Coventry, UK.

Hambly, E. , and Suttle, C. A. (2005) The virosphere, diversity, and genetic exchange within phage communities. *Curr Opin Microbiol* 8: 444-450.

Hambly, E. , Tétart, F. , Desplats, C. , Wilson, W. H. , Krisch, H. M. , and Mann, N. H. (2001) A conserved genetic module that encodes the major virion components in both coliphage T4 and the marine cyanophages S-PM2. *Proc Natl Acad Sci USA* 98: 11411-11416.

Handelsman, J. (2004) Metagenomics: Application of genomics to uncultured organisms. *Microbiol Mol Biol Rev* 69: 669-685.

Handelsman, J. , Rondon, R. , Brady, S. F. , Clardy, J. , and Goodman, R. M. (1998) Molecular biological access to the chemistry of unknown soil microbes: A new frontier for natural products. *Chem Biol* 5: R245-R249.

Hannen, E. J. , Zwart, G. , van Agterveld, M. P. , Gons, H. J. , Ebert, J. , and Laanbroek, H. J. (1999) Bacterial and eukaryotic community structure after mass lysis of filamentous cyanobacteria associated with viruses. *Appl Environ Microbiol* 65: 795-801.

Hara, S. , Terauchi, K. , and Koike, I. (1991) Abundance of viruses in marine waters: Assessment of epifluorescence and transmission electron microscopy. *Appl Environ Microbiol* 57: 2731-2734.

He, Q. , Dolganov, N. , Björkman, O. , and Grossman, A. R. (2001) The high light inducible polypeptides in *Synechocystis* PCC6803: expression and function in high light. *J Biol Chem* 276: 306-314.

Heldal, M. , and Bratbak, G. (1991) Production and decay of viruses in aquatic environments. *Mar Ecol Prog Ser* 72: 205-212.

Hendrix, R. W. (2003) Bacteriophage genomics. *Curr Opin Microbiol* 6: 506-511.

Hennes, K. P. , and Suttle, C. A. (1995) Direct counts of viruses in natural sea water and laboratory cultures by epifluorescence microscopy. *Limnol Oceanogr* 40: 1054-1059.

Hennes, K. P. , Suttle, C. A. , and Chan, A. M. (1995) Fluorescently labeled virus probes show that natural virus populations can control the structure of marine microbial communities. *Appl Environ Microbiol* 61: 3623-3627.

Hess, W. R. , Partensky, F. , Van Der Staay, G. W. M. , Garcia-Fernandez, J. M. , Borner, T. , and Vaultot, D. (1996). Coexistence of phycoerythrin and a chlorophyll a/b antenna in a marine prokaryote. *Proc.Natl Acad Sci USA* 93: 11126-11130.

Hewson, I. , O'Neil, J. M. , and Dennison, W. C. (2001) Virus-like particles associated with *Lyngbya majuscula* (Cyanophyta, Oscillatoriaceae) bloom decline in Moreton Bay, Australia. *Aquat Microb Ecol* 25: 207-213.

Hill, R. W. , Wb, A. , Cottrell, M. T. , and Dacey, J. W. H. (1998) Virus-mediated total release of dimethylsulfoniopropionate from marine phytoplankton: a potential climate process. *Aquat Microb Ecol* 14: 1-6.

Hirons, G. T. , Fawcett, J. J. , and Crissman, H. A. (1994) TOTO and YOYO: New very bright fluorochromes for DNA content analysis by flow cytometry. *Cytometry* 15: 129-140.

Honjo, M. , Matsui, K. , Ueki, M. , Nakamura, R. , Fuhrman, J. A. , and Kawabata, Z. (2006) Diversity of virus-like agents killing *Microcystis aeruginosa* in a hypereutrophic pond. *J Plankton Res* 28: 407-412.

Hu, N.-T. , Thiel, T. , Giddings, T. H. , and Wolk, C. P. (1981) New *Anabaena* and *Nostoc* cyanophages from sewage settling ponds. *Virology* 114: 236-246.

Hwang-Lee, L. , Blashka, K. H. , Blamire, J. , and McGowan, R. E. (1982a) DNA metabolism during infection of *Anacystis nidulans* by cyanophage AS-1: 1. Identification of a unique species of DNA. *Microbios* 35: 49-62.

Hwang-Lee, L. , Blashka, K. H. , McGowan, R. E. , and Blamire, J. (1982b) DNA metabolism during infection of *Anacystis nidulans* by cyanophage AS-1: 2. Analysis of DNA synthesis patterns and discrimination of precursor utilization. *Microbios* 36: 111-118.

Hwang-Lee, L. , Cohn, G. , Blashka, K. H. , Blamire, J. , and McGowan, R. E. (1983a) DNA metabolism during infection of *Anacystis nidulans* by cyanophage AS-1: 4. Studies on source of PIL-DNA. *Microbios* 36: 101-112.

Hwang-Lee, L. , Cohn, G. , Blashka, K. H. , McGowan, R. E. , and Blamire, J. (1983b) DNA metabolism during infection of *Anacystis nidulans* by cyanophage AS-1: 5. Biophysical characterization of phage-induced light DNA. *Microbios* 36: 191-208.

Inoue, T. , Matsuzaki, S. , and Tanaka, S. (1995) A 26 kDa outer membrane protein, OmpK, common to *Vibrio* species is the receptor for broad-host-range vibriophage, KVP40. *FEMS Microbiol Lett* 125: 101-105.

Jameson, E. , Mann, N. H. , Joint, H. , Sambles, C. , and Mühling, M. (2011) The diversity of cyanomyovirus populations along a North-South Atlantic Ocean transect. *Isme J* 5: 1713-1721. doi:<https://doi.org/10.1038/ismej.2011.54>

Jenkins, C. A. , and Hayes, P. K. (2006) Diversity of cyanophages infecting the heterocystous filamentous cyanobacterium *Nodularia* isolated from the brackish Baltic Sea. *J Mar Biol Ass UK* 86: 529-536.

Jia, Y. , Ying, S. , Shan, J. , Millard, A. , Clokie, M. R. , and Mann, N. H. (2010) Light-dependent adsorption of photosynthetic cyanophages to *Synechococcus* sp. WH7803. *FEMS Microbiol Lett* 310: 120-126.

Jia, Z. , Ishihara, R. , Nakajima, Y. , Asakawa, S. , and Kimura, M. (2006) Molecular characterization of T4-type bacteriophages in a rice field. *Environ Microbiol* 9: 1091-1096. doi:<https://doi.org/10.1111/j.1462-2920.2006.01207.x>

Jiang, S. , Steward, G. , Jellison, R. , Chu, W. , and Choi, S. (2004) Abundance, distribution and diversity of viruses in alkaline, hypersaline Mono Lake, California. *Microb Ecol* 47: 30-40.

Joint, I. R. , and Pomroy, A. J. (1983) Production of picoplankton and small nanoplankton in the Celtic Sea. *Mar Biol* 77: 19-27.

Kao, C. C. , Green, S. , Stein, B. , and Golden, S. S. (2005) Diel infection of a cyanobacterium by a contractile bacteriophage. *Appl Environ Microbiol* 71: 4276-4279.

Kashyap, A. K. , and Singh, S. (1989) Changes in photoelectron transport activity in cyanophage N-1 infected cells of *Nostoc muscorum*. *Current Microbiol* 18: 151-155.

Kashyap, A. K. , Rai, A. N. , and Singh, S. (1988) Effect of cyanophage N-1 development on nitrogen metabolism of cyanobacterium *Nostoc muscorum*. *FEMS Microbiol Lett* 51: 145-148.

Kaushik, B. D. , and Venkataraman, G. S. (1973) Isolation of a new cyanophage TAUHN-1. *Curr Sci* 42: 395-396.

Kepner, R. J. , Wharton, R. J. , and Suttle, C. (1998) Viruses in Antarctic lakes. *Limnol Oceanogr* 42: 1754-1761.

Khudyakov, I. Ya . (1977) Characteristics of a new cyanophage S-2(L) lysing the unicellular cyanobacterium belonging to *Synechococcus* genus. *Mikrobiologiya*. 46: 547-553.

Khudyakov, I. Ya., and Gromov, B. V. (1973) The temperate cyanophage A-4 (L) of the blue-green alga *Anabaena variabilis*. *Mikrobiologiya* 42: 904-907.

Khudyakov, I. Ya., and Matveyev, A. V. (1981) Comparative characteristics of cyanophages of unicellular cyanobacterium *Synechococcus* sp. 698. In: *Viruses of Microorganisms*. Academy of Nauk SSSR, Pushchino. pp. 104-106.

Khudyakov, I. Ya., and Matveyev, A. V. (1982) New cyanophages S-4(L) and S-5(L) causing lysis of the cyanobacterium *Synechococcus elongatus*. *Mikrobiologiya* 51: 102-106.

Khudyakov, I. Ya., Kirnos, M. D. , Alexandrushkina, N. I. , and Vanyushin, B. F. (1978) Cyanophage S-2L contains DNA with 2,6-diaminopurine substituted for adenine. *Virology* 88: 8-18.

Kim, M. , and Choi, Y.-K. (1994) A new *Synechococcus* cyanophage from a reservoir in Korea. *Virology* 204: 338-342.

Koz'yakov, S. Ya . (1977) Cyanophages of the series A(L) specific for the blue-green alga, *Anabaena variabilis*. *Ekspperimental' naya al'gologiya. Trudi Petergof Biol Inst (Leningrad State University)* 25: 151-175.

Koz'yakov, S. Ya . (1981) Characteristics of a new cyanophage for the cyanobacterium *Synechococcus schmidlea*. *Mikrobiologiya*. 50: 543-549.

Koz'yakov, S. Ya . (1982). Peculiarities of a new cyanophage specific for the cyanobacterium *Synechococcus schmidlea*. *Microbiology (New York)* 50: 395-401.

Koz'yakov S. Ya., Gromov B. V. , Khudyakov I. Y. (1972) A-1(L) cyanophage of the blue-green alga *Anabaena variabilis*. *Mikrobiologiya* 41: 555-559.

Krauss, R. W. (1961) *Algae and Metropolitan Wastes*. Trans of 1960 Seminar. Tech. Report W60-3, Robert A. Taft Engineering Corporation. US Public Health Service, Cincinnati, Ohio, USA. p. 40.

Kurmayer, R. , and Kutzenberg, T. (2003) Application of real-time PCR for quantification of microcystin genotypes in a population of the toxic cyanobacterium *Microcystis* sp. *Appl Environ Microbiol* 69: 6723-6730.

Kuno, S. , Yoshida, T. , Kamikawa, R. , Hosada, N. , and Sako, Y. (2010) The distribution of a phage-related insertion sequence element in the cyanobacterium, *Microcystis aeruginosa*. *Microbes Environ* 25: 295-301. doi:<https://doi.org/10.1264/jsme2.ME.10125>

La Roche, J. , Van Der Staay, G. W. M. , Partensky, F. , Ducret, A. , Aebersold, R. , Li, R. , Golden, S. S. , Hiller, R. G. , Wrench, P. M. , Larkum, A. W. D. , and Green, B. R. (1996). Independent evolution of the prochlorophyte and green plant chlorophyll a/b light-harvesting proteins. *Proc. Natl. Acad. Sci. USA* 93: 15244-15248.

Lambert, G. R. , and Carr, N. G. (1984) Resistance of DNA from filamentous and unicellular cyanobacteria to restriction endonuclease cleavage. *Biochem Biophys Acta* 781: 45-55.

Lane, D. J. , Pace, B. , Olsen, G. J. , Stahl, D. J. , Sogin, M. L. , and Pace, N. R. (1985) Rapid determination of 16S ribosomal RNA sequences for phylogenetic analyses. *Proc Natl Acad Sci USA* 82: 6955-6959.

Leach, J. E. , Lee, K. W. , Benson, R. L. , and Martin, E. L. (1980) Ultrastructure of the infection cycle of cyanophage SM-2 in *Synechococcus elongatus* (Cyanophyceae). *J Phycol* 16: 307-310.

Lehmann, J. , Volkl, W. , Udvardy, J. , Borbely, G. , Sivok, S. , and Farkas, G. L. (1979) Characterization of a ribonuclease from *Anacystis nidulans* infected with cyanophage AS-1. *Phytochemistry* 18: 541-544.

Lennon, J. T. , Khatana, S. A. M. , Marston, M. F. , and Martiny, J. B. H. (2007) Is there a cost of virus resistance in marine cyanobacteria? *Isme J* 1: 300-312. www.nature.com/ismej

Lewin, R. A. (1963) Rod-shaped particles of *Saprospira*. *Nature (London)* 198: 103-104.

Li, W. K. W. , Subba Rao, D. V. , Harrison W. G. , Smith, J. C. , Cullen, J. J. , Irwin, B. , and Platt, T. (1983) Autographic picoplankton in the tropical ocean. *Science* 219: 292-295.

Lichtle, C. , Thomas, J. C. , Spilar, A. , and Partensky, F. (1995). Immunological and ultrastructural characterization of the photosynthetic complexes of the prochlorophyte *Prochlorococcus* (oxychlorobacteria) 1. *J Phycol* 31: 934-941.

Lindell, D. , Jaffe, J. D. , Johnson, Z. I. , Church, G. M. , and Chisholm, S. W. (2005) Photosynthesis genes in marine viruses yield proteins during host infection. *Nature (London)* 438: 86-89.

Lindell, D. , Jaffe, J. D. , Coleman, M. L. , Futschik, M. E. , Axman, I. M. , Rector, T. , Kettler, G. , Sullivan, M. B. , Steen, R. , Hess, W. R. , Church, G. M. , and Chisholm, S. W. (2007) Genome wide expression dynamics of a marine virus and host reveal features of co-evolution. *Nature (London)* 449: 83-86.

Lindell, D. , Sullivan, M. B. , Johnson, Z. I. , Tolonen, A. C. , Rohwer, F. , and Chisholm, S. W. (2004) Transfer of photosynthesis genes to and from *Prochlorococcus* viruses. *Proc Natl Acad Sci USA* 101: 11013-11018.

Liu, H. , Campbell, L. , Landry, M. R. , Nolla, H. A. , Brown, S. L. , and Constantinou, J. (1998) *Prochlorococcus* and *Synechococcus* growth rates and contributions to production in the Arabian Sea during the 1995 Southwest and Northeast monsoons. *Deep Sea Res II* 45: 2327-2352.

- Liu, H. , Nolla, H. A. , and Campbell, L. (1997) Prochlorococcus growth rate and contribution to primary production in the equatorial and subtropical North Pacific Ocean. *Aquat Microb Ecol* 12: 39-47.
- Liu, X. , Shi, M. , Kong, S. , Gao, Y. , and An, C. (2007) Cyanophage Pf-WMP4, a T7 like phage infecting the freshwater cyanobacterium *Phormidium foveolarum*: Complete genome sequence and DNA translation. *Virology* 366: 28-39.
- Long, A. , McDaniel, L. D. , Mobberley, J. , and Paul, J. H. (2008) Comparison of lysogeny (prophage induction) in heterotrophic bacterial and *Synechococcus* populations in the Gulf of Mexico and Mississippi river plume. *Isme J* 2: 132-144.
- Lu, J. , Chen, F. , and Hodson, R. E. (2001) Distribution, isolation, host specificity and diversity of cyanophages infecting marine *Synechococcus* spp. in river estuaries. *Appl Environ Microbiol* 67: 3285-3290.
- Luftig, R. , and Haselkorn, R. (1967) Morphology of a virus of blue-green algae and properties of its deoxyribonucleic acid. *J Virol* 1: 344-361.
- Luftig, R. , and Haselkorn, R. (1968a) Studies on the structure of blue-green algae virus LPP-1. *Virology* 34: 644-674.
- Luftig, R. , and Haselkorn, R. (1968b) Comparison of blue-green algae virus LPP-1 and the morphologically related viruses GIII and coliphage T7. *Virology* 34: 675-678.
- Mackenzie, J. J. , and Haselkorn, R. (1972a) Physical properties of blue-green algal virus SM-1 and its DNA. *Virology* 49: 497-504.
- Mackenzie, J. J. , and Haselkorn, R. (1972b) An electron microscope study of infection by the blue-green algal virus SM-1. *Virology* 49: 505-516.
- Mackenzie, J. J. , and Haselkorn, R. (1972c) Photosynthesis and the development of blue-green algal virus SM-1. *Virology* 49: 517-521.
- Magnusson, L. U. , Farewell, A. , and Nystrom, T. (2005) ppGpp: A global regulator in *Escherichia coli*. *Trends Microbiol* 13: 236-242.
- Malin, G. , Wilson, W. H. , Bratbak, G. , Liss, P. S. , and Mann, N. H. (1998) Elevated production of dimethylsulfide resulting from viral infection of cultures of *Phaeocystis pouchetii*. *Limnol Oceanogr* 43: 1389-1393.
- Mamkayeva, K. A. , Al-Musavi, R. A. , and Gromov, B. V. (1980) The effect of photosynthesis in the ultrastructure of a cyanophage during its intracellular growth. *Mikrobiologiya* 49: 631-633.
- Manage, P. M. , Kawabata, Z. , and Nakano, S.-I. (1999) Seasonal changes in densities of cyanophages infectious to *Microcystis aeruginosa* in hypereutrophic pond. *Hydrobiologia* 411: 211-216.
- Mann, N. H. (2003) Phages of marine cyanobacterial picoplankton. *FEMS Microbiol Rev* 27: 17-34.
- Mann, N. H. (2005) The third age of phage. *PLoS Biol* 3: e182. doi:<https://doi.org/10.1371/journal.pbio.0030182>
- Mann, N. H. , Ahlgren, N. , Moffett, J. W. , and Chisholm, S. W. (2002) Copper toxicity and cyanobacteria ecology in the Sargasso Sea. *Limnol Oceanogr* 47: 976-988.
- Mann, N. , Carr, N. G. , and Midgley, J. E. (1975) RNA synthesis and the accumulation of guanine nucleotides during growth shift down in the blue-green alga *Anacystis nidulans*. *Biochim Biophys Acta* 402: 41-50.
- Mann, N. H. , Clorkie, M. R. J. , Millard, A. J. , Cook, A. , Wilson, W. H. , Wheatley, P. J. , Letarov, A. , and Krisch, H. M. (2005) The genome of S-PM2, a "photosynthetic" T4-type bacteriophage that infects marine *Synechococcus* strains. *J Bacteriol* 187: 3188-3200.
- Mann, N. H. , Cook, A. , Millard, A. , Bailey, S. , and Clorkie, M. (2003) Marine ecosystems: Bacterial photosynthesis genes in a virus. *Nature (London)* 424: 741.
- Marie, D. , Brussaard, C. P. D. , Thyraug, R. , Bratbak, G. , and Vaulot, D. (1999) Enumeration of marine viruses in culture and natural samples by flow cytometry. *Appl Environ Microbiol* 65: 45-52.
- Marston, M. , and Amrich, C. G. (2009) Recombination and microdiversity in coastal marine cyanophages. *Environ Microbiol* 11: 2893-2903.
- Marston, M. F. , and Sallee, J. L. (2003) Genetic diversity and temporal variation in the cyanophage community infecting marine *Synechococcus* species in Rhode Island's coastal waters. *Appl Environ Microbiol* 69: 4639-4647.
- Mathews, R. E. F. (1979) Classification and nomenclature of viruses. Third report of the International Committee on Taxonomy of viruses. *Intervirology* 12: 129-296.
- Mayer, J. A. , and Taylor, F. J. R. (1979) A virus which lyses the marine nanoflagellate *Micromonas pusilla*. *Nature (London)* 281: 299-301.
- McDaniel, L. , and Paul, J. H. (2005) Effect of nutrient addition and environmental factors on prophage induction in natural populations of marine *Synechococcus* species. *Appl Environ Microbiol* 71: 842-850.
- McDaniel, L. , de la Rosa, M. , and Paul, J. H. (2006) Temperate and lytic cyanophages from the Gulf of Mexico. *J Mar Biol Ass UK* 86: 517-527.
- McDaniel, L. , Houchin, L. A. , Williamson, S. J. , and Paul, J. H. (2002) Lysogeny in marine *Synechococcus*. *Nature (London)* 415: 496. www.nature.com
- Mendzhul, M. I. , Karnaukhov, V. N. , Martsenyuk, P. P. , and Grigoryas, V. A. (1982) Features of interaction between virus and cell in cyanophage-cyanobacteria system. *Mikrobiol ZH (Kiev)* 44: 63-70.
- Mendzhul, M. I. , Lysenko, T. G. , and Semenova, G. A. (1983) Biological and physicochemical properties of N-2. *Mikrobiol ZH (Kiev)* 45: 60-66.
- Mendzhul, M. I. , Lysenko, T. G. , Shainkskaya, O. A. , and Gerashchenko, I. V. (1988) Changes in the specific activity of glucose-6-phosphate dehydrogenase in cyanophage LPP-3-cyanobacterium *Plectonema boryanum*. *Mikrobiol ZH (Kiev)* 50: 88-89.
- Middelboe, M. , Jorgensen, N. O. G. , and Kroer, N. (1996) Effects of viruses on nutrient turnover and growth efficiency of non-infected marine bacterioplankton. *Appl Environ Microbiol* 62: 1991-1997.
- Middelboe, M. , Riemann, L. , Steward, G. F. , Hansen, V. , and Nybroe, O. (2003) Virus-induced transfer of organic carbon between marine bacteria in a model community. *Aquat Microb Ecol* 33: 1-10.
- Millard, A. , Clorkie, M. R. , Shub, D. A. , and Mann, N. H. (2004) Genetic organization of the psbAD region in phages infecting marine *Synechococcus* strains. *Proc Natl Acad Sci USA* 101: 11007-11012.
- Millard, A. D. , Gierga, G. , Clorkie, M. R. , Evans, D. J. , Hess, W. R. , and Scanlan, D. J. (2010) An antisense RNA in a lytic cyanophage links psbA to a gene encoding a homing endonuclease. *Isme J* 4: 1121-1135. doi: <https://doi.org/10.1038/ismej.2010.43>
- Millard, A. D. , Zwirglaier, K. , Downey, M. J. , Mann, N. H. , and Scanlan, D. J. (2009) Comparative genomics of marine cyanomyoviruses reveals the widespread occurrence of *Synechococcus* host genes localized to a hyperplastic region: Implications for mechanisms of cyanophage evolution. *Environ Microbiol* 11: 2370-2387.
- Miller, E. S. , Heidelberg, J. F. , Eisen, J. A. , Nelson, W. C. , Durkin, A. S. , Ciecko, A. , Feldblyum, T. V. , White, O. , Paulsen, I. T. , Niernan, W. C. , Lee, J. , Szczynski, B. , and Fraser, C. M. (2003) Complete genome sequence of the broad-host-range vibriophage KVP40: Comparative genomics of a T4-related bacteriophage. *J Bacteriol* 185: 5220-5223.

Moisa, I. , Sotropa, E. , and Velehorsch, V. (1981a) Investigations on the presence of cyanophages in fresh and seawaters of Romania. *Rev Roum Med Virol* 32: 127-132.

Moisa, I. , Sotropa, E. , and Velehorsch, V. (1981b) Sequence of morphological alterations in blue-green algae in the course of cyanophage infection. *Virologie* 32: 133-137.

Moore, L. R. , Rocap, G. , and Chisholm, S. W. (1998) Physiology and molecular phylogeny of co-existing *Prochlorococcus* ecotypes. *Nature (London)* 393: 464-467.

Mühling, M. , Fuller, N. J. , Millard, A. , Somerfield, P. J. , Marie, D. , Wilson, W. H. , Scanlan, D. J. , Post, A. F. , Joints, I. , and Mann, N.H. (2005) Genetic diversity of marine *Synechococcus* and co-occurring cyanophage communities. Evidence for viral control of phytoplankton. *Environ Microbiol* 7: 499-508.

Mulo, P. , Eloranta, T. , Aro, E. M. , and Maenpää, P. (1998) Disruption of a spe-like open reading frame alters polyamine content and psbA-2 mRNA stability in the cyanobacterium *Synechocystis* sp. PCC 6803. *Bot Acta* 111: 71-76.

Muradov, M. , Cherkasov, G. V. , Akhmedova, D. U. , and Khalmuradov, A. G. (1990a) A new temperate cyanophage NP-1T lysogenizing cyanobacterial cultures belonging to the genera *Nostoc* and *Plectonema*. *Microbiologiya* 59: 1038-1045.

Muradov, M. , Cherkasov, G. V. , Akhmedova, D. U. , Kamilova, F. D. , Mukhamedov, R. S. , Abdulkarimov, A. A. , and Khalmuradov, A. G. (1990b) Comparative study of NP-1T cyanophage, which lysogenize nitrogen-fixing bacteria of the genera *Nostoc* and *Plectonema*. *Microbiologiya* 59: 558-563.

Noble, R. T. , and Fuhrman, J. A. (1998) Use of SYBR Green I for rapid epifluorescence counts of marine viruses and bacteria. *Aquat Microb Ecol* 14: 113-118.

O'Connell, D. (2005) Viral genomics: Small is beautiful. *Nat Rev Microbiol* 3: 520.

Ohki, K. (1999) A possible role of temperate phage in the regulation of *Trichodesmium* biomass. *Bull Inst Oceanogr Monaco* 19: 287-292.

Ohki, K. , and Fujita, Y. (1996) Occurrence of a temperate cyanophage lysogenizing the marine cyanophyte *Phormidium persicinum*. *J Phycol* 32: 365-370.

Okunishi, S. , Yoshimura, N. , Maeda, H. , Yoshikawa, T. , and Sakata, T. (2002) Isolation and characterization of a cyanophage infecting cyanobacterial picoplankton, *Synechococcus* sp. from Kagoshima Bay. *Microbes Environ* 17: 148-152.

Okunishi, S. , Yoshimura, N. , Maeda, H. , Yoshikawa, T. , and Sakata, T. (2003) A virulent cyanophage affects the seasonal abundance of cyanobacterial picoplankton (*Synechococcus* sp.) in Kagoshima Bay. *Microbes Environ* 18: 10-15.

Olivera, A. R. , Mudd, J. B. , and Desjardins, P. R. (1982) AS-1 Cyanophage adsorption to liposomes. *J Gen Virol* 61: 153-156.

Oren, A. , Bratba, G. , and Heldal, M. (1997) Occurrence of virus-like particles in the Dead Sea. *Extremophiles* 1: 143-149.

Ortmann, A. C. , Lawrence, J. E. , and Suttle, C. A. (2002) Lysogeny and lytic viral production during a bloom of the cyanobacterium *Synechococcus* spp. *Microb Ecol* 43: 225-231.

Padan, E. , and Shilo, M. (1969) Distribution of cyanophages in natural habitats. *Verh Int Verein Limnol* 17: 747-751.

Padan, E. , and Shilo, M. (1973) Cyanophages-Viruses attacking blue-green algae. *Bacteriol Rev* 37: 343-370.

Padan, E. , Ginzburg, D. , and Shilo, M. (1970) The reproductive cycle of cyanophage LPP1-G in *Plectonema boryanum* and its dependence on photosynthetic and respiratory system. *Virology* 40: 514-521.

Padan, E. , Raboy, B. , and Shilo, M. (1971a) Endogenous dark respiration of the blue-green alga, *Plectonema boryanum*. *J Bacteriol* 106: 45-50.

Padan, E. , Rimon, A. , Ginzberg, D. , and Shilo, M. (1971b) A thermosensitive cyanophage (LPP1-G) attacking the blue-green alga *Plectonema boryanum*. *Virology* 45: 773-776.

Padan, E. , Shilo, M. , and Kislev, N. (1967) Isolation of "cyanophages" from freshwater ponds and their interaction with *Plectonema boryanum*. *Virology* 32: 234-246.

Padan, E. , Shilo, M. , and Oppenheim, A. B. (1972) Lysogeny of the blue-green alga *Plectonema boryanum* by LPP2-SPI cyanophage. *Virology* 47: 525-526.

Padhy, R. N. , and Singh, P. K. (1977a) Effects of physical and chemical agents on the blue-green algal virus N-1. *Acta Virol* 21: 264-267.

Padhy, R. N. , and Singh, P. K. (1977b) Effect of temperature on adsorption and one-step growth of the *Nostoc* virus N-1. *Arch Microbiol* 155: 163-167.

Padhy, R. N. , and Singh, P. K. (1978a) Stabilizing effects of metallic ions in the blue-green algal virus N-1. *Biochem Physiol Pflanzen* 173: 188-192.

Padhy, R. N. , and Singh, P. K. (1978b) Effect of host aging, ions and pH on the adsorption of cyanovirus N-1 to *Nostoc muscorum*. *Arch Microbiol* 156: 289-292.

Partensky, F. , Hess, W. R. , and Vaulot, D. (1999) *Prochlorococcus*, a marine photosynthetic prokaryote of global significance. *Microbiol Mol Biol Rev* 63: 106-127.

Paul, J. H. , and Sullivan, M. B. (2005) Marine phage genomics: What we learned? *Curr Opin Biotechnol* 16: 299-307.

Paul, J. H. , Jiang, S. C. , and Rose, J. B. (1991) Concentration of viruses and dissolved DNA from aquatic environments by vortex flow filtration. *Appl Environ Microbiol* 57: 2197-2204.

Pedros-Alio, C. , Calderon, Paz J. , MacLean, M. , Medina, G. , Marrase, C. , Gasol, J. , and Boixereu, N. (2000a) The microbial food web along salinity gradients. *FEMS Microbiol Ecol* 32: 143-155.

Pedros-Alio, C. , Calderon-Paz, J. , and Gasol, J. (2000b) Comparative analysis shows that bacteriophage, not viral lysis, controls the abundance of heterotrophic prokaryotic plankton. *FEMS Microbiol Ecol* 32: 157-165.

Pedulla, M. L. , Ford, M. E. , Houtz, J. M. , Karthikeyan, T. , Wadsworth, C. , Lewis, J. A. , Jacobs-Sera, D. , Falbo, J. , Gross, J. , Pannunzio, N. R. , Brucker, W. , Kumar, V. , Kandasamy, J. , Keenan, L. , Bardarov, S. , Kirakov, J. , Lawrence, J. G. , Jacobs, W. R. Jr. , Hendrix, R. W. , and Hatfull, G. F. (2003) Origins of highly mosaic mycobacteriophage genomes. *Cell* 113: 171-182.

Philosof, A. , Battchikova, N. , Aro, E-M. , and Béjà, O. (2011) Marine cyanophages: Tinkering with the electron transport chain. *Isme J* 5: 1568-1570.

Philips, E. J. , Monegue, R. L. , and Aldridge, F. J. (1990) Cyanophages which impact bloom-forming cyanobacteria. *J Aquat Plant Manag* 28: 92-97.

Pollard, P. C. , and Young, L. M. (2009) Lake viruses lyse cyanobacteria, *Cylindrospermopsis raciborskii*, enhances filamentous- host dispersal in Australia. *Acta Oecologica* 36: 114-119.

Pope, W. H. , Weigele, P. R. , Chang, J. , Pedulla, M. L. , Ford, M. E. , Houtz, J. M. , Jiang, W. , Chiu, W. , Hatfull, G. F. , Hendrix, R. W. , and King, J. (2007). Genome sequence, structural proteins, and capsid organization of the cyanophages Syn5: A "horned" bacteriophage of marine *Synechococcus*. *J Mol Biol* 368: 966-981.

Proctor, L. M. , and Fuhrman, J. A. (1990) Viral mortality of marine bacteria and cyanobacteria. *Nature (London)* 343: 60-62.

Proctor, L. M. , and Fuhrman, J. A. (1991) Roles of virus infection in organic particle flux. *Mar Ecol Prog Ser* 69: 133-142.

Proctor, L. M. , and Fuhrman, J. A. (1992) Mortality of marine bacteria in response to enrichments of the virus size fraction from seawater. *Mar Ecol Prog Ser* 87: 283-293.

Rautenstein, Y. J. , Stefanov, S. B. , Smirnova, E. I. , and Khadjimurti, L. N. (1966) On defective lysogeny in *Actinomyces streptomycini* Kras. *Microbiology* 30: 860-863.

Raytcheva, D. A. , Haase-Pettingell, C. , Piret, J. H. , and King, J. (2010) Intracellular assembly of cyanophage Syn5 proceeds through a scaffold-containing procapsid. *J Virol* doi:<https://doi.org/10.1128/JVI.01601-10>.

Rimon, A. , and Oppenheim, A. B. (1975) Heat induction of the blue-green alga *Plectonema boryanum* lysogenic for cyanophages SPI cts1. *Virology* 64: 454-463.

Rocap, G. , Larimer, F. W. , Lamerdin, J. , Malfatti, S. , Chain, P. , Ahlgren, N. A. , Arellano, A. , Coleman, M. , Hauser, L. , Hess, W. R. , Johnson, Z. I. , Land, M. , Lindell, D. , Post, A. F. , Regala, W. , Shah, M. , Shaw, S. L. , Steglich, C. , Sullivan, M. , Ting, C. S. , Tolonen, A. , Webb, E. A. , Zinser, E. R. , and Chisholm, S. W. (2003) Genome divergence in two *Prochlorococcus* ecotypes reflects oceanic niche differentiation. *Nature (London)* 424: 1042-1047.

Rohwer, F. , and Edwards, R. (2002) The phage proteomic tree: Genome based taxonomy for phage. *J Bacteriol* 184: 4529-4535.

Ruardij, P. , Veldhuis, M. J. W. , and Brussaard, C. P. D. (2005) Modeling the bloom dynamics of the polymorphic plankter *Phaeocystis globosa*: Impact of grazers and viruses. *Harmful Algae* 4: 941-963.

Rusch, D. B. , Halpem, A. L. , Sutton, G. , Heidelberg, K. B. , Williamson, S. , Yooseph, S. , Wu, D. , Eisen, J. A. , Hoffman, J. M. , Remington, K. , Beeson, K. , Tran, B. , Smith, H. , Baden-Tillson, H. , Stewart, C. , Thorpe, J. , Freeman, J. , Andrews-Pfankoch, C. , Venter, J. E. , Li, K. , Kravitz, S. , Heidelberg, J. F. , Utterback, T. , Rogers, Y.-H. , Falcon, L. I. , Souza, V. , Bonilla-Rosso, G. , Eguiarte, C. E. , Karl, D. M. , Sathyendranath, S. , Platt, T. , Bermingham, E. , Gallardo, V. , Tomayo-Castillo, G. , Ferrari, M. R. , Strausberg, R. L. , Neelson, K. , Friedman, R. , Frazier, M. , and Venter, J. C. (2007) The Sorcerer II global ocean sampling expedition: Northwest Atlantic through eastern tropical Pacific. *PLoS Biol* 5: e77.

Safferman, R. S. , and Morris, M. E. (1963) Algal virus: Isolation. *Science* 140: 679-680.

Safferman, R. S. , and Morris, M. E. (1964a) Growth characteristics of the blue-green algal virus LPP-1. *J Bacteriol* 88: 771-775.

Safferman, R. S. , and Morris, M. E. (1964b) Control of algae with viruses. *J Am Water Works Ass* 56: 1217-1224.

Safferman, R. S. , and Morris, M. E. (1967) Observations on the occurrence, distribution, and seasonal incidence of blue-green algal viruses. *Appl Microbiol* 15: 1219-1222.

Safferman, R. S. , Cannon, R. F. , Desjardins, P. R. , Gromov, B. V. , Haselkorn, R. , Sherman, L. A. , and Shilo, M. (1983) Classification and nomenclature of viruses of cyanobacteria. *Intervirology* 19: 61-66.

Safferman, R. S. , Diener, T. O. , Desjardins, P. R. , and Morris, M. E. (1972) Isolation and characterization of AS-1, a phycovirus infecting the blue-green algae *Anacystis nidulans* and *Synechococcus cedrorum*. *Virology* 47: 105-113.

Safferman, R. S. , Schneider, I. R. , Steere, R. L. , Morris, M. E. , and Diener, T. O. (1969a) Phycovirus SM-1: A virus infecting unicellular blue-green algae. *Virology* 37: 386-395.

Safferman, R. S. , Morris, M. E. , Sherman, L. A. , and Haselkorn, R. (1969b) Serological and electron microscopic characterization of a new group of blue-green algal viruses (LPP-2). *Virology* 39: 775-780.

Samami, B. , and Drews, G. (1978) Adsorption of cyanophage AS-1 to unicellular cyanobacteria and isolation of receptor material from *Anacystis nidulans*. *J Virol* 25: 164-174.

Sanda, R.-A. , and Larsen, A. (2006) Seasonal variations in virus-host populations in Norwegian coastal waters: Focusing on the cyanophage community infecting marine *Synechococcus* spp. *Appl Environ Microbiol* 72: 4610-4618.

Sanda, R. A. , Clokie, M. , and Mann, N. H. (2008) Photosynthetic genes in viral populations with a large genome size range from Norwegian coastal waters. *FEMS Microbiol Ecol* 63: 2-11.

Sano, E. , Carlson, S. , Wegley, L. , and Rohwer, F. (2004) Movement of viruses between biomes. *Appl Environ Microbiol* 70: 5842-5846.

Sarma, T. A. , and Kaur, B. (1993) Spontaneous and induced host-range mutants of cyanophage N-1. *Arch Virol* 130: 195-200.

Sarma, T. A. , and Kaur, B. (1997) Characterization of host-range mutants of cyanophage N-1. *Acta Virol* 41: 245-250.

Sarma, T. A. , and Kaur, S. P. (2005) Development of cyanophage N-1 under heavy metal stress. *Acta Virol* 49: 23-28.

Sarma, T. A. , and Singh, R. (1994) Isolation and characterization of temperature-sensitive mutants of cyanophage N-1. *Acta Virol* 38: 11-16.

Sarma, T. A. , and Singh, R. (1995) Characterization of ts-mutants of cyanophage N-1 by their inactivation by physical and chemical agents. *Acta Virol* 39: 65-68.

Schloss, P. D. , and Handelsman, J. (2005) Metagenomics for studying unculturable microorganisms: Cutting the Gordian knot. *Genome Biol* 6: 229. <http://genomebiology.com/2005/6/8/229>

Schmidt, T. M. , DeLong, E. F. , and Pace, N. R. (1991) Analysis of a marine picoplankton community by 16S rRNA gene cloning and sequencing. *J Bacteriol* 173: 4371-4378.

Schneider, G. J. , and Haselkorn, R. (1988) Characterization of two early promoters of cyanophage N-1. *Virology* 167: 150-155.

Schneider, I. R. , Diener, T. O. , and Safferman, R. S. (1964) Blue-green algal virus LPP-1: purification and partial characterization. *Science* 144: 1127-1130.

Shane, M. S. (1971) Distribution of blue-green algal viruses in various types of natural waters. *Water Res* 5: 711-716.

Sharma, C. R. , and Venkataraman, G. S. (1977) Cyanophage AC-1 infecting blue-green alga *Anacystis nidulans*. *Curr Sci* 46: 496-497.

Sharma, C. R. , and Venkataraman, G. S. (1978) Seasonal periodicity of cyanophage AC-1. *Curr Sci* 47: 914-915.

Sharon, I. , Alperovitch, A. , Rohwer, F. , Haynes, M. , Glaser, F. , Atamna-Ismaeel, N. , Pinter, R. Y. , Partensky, F. , Koonin, E. V. , Wolf, Y. I. , Nelson, N. , and Béjà, O. (2009) Photosystem I gene cassettes are present in marine virus genomes. *Nature (London)* 461: 258-261. doi:<https://doi.org/10.1038/nature08284>

Sharon, I. , Battchikova, N. , Aro, E.-M. , Giglione, C. , Meinel, T. , Glaser, F. , Pinter, R. Y. , Breitbart, M. , Rohwer, F. , and Béjà, O. (2011) Comparative metagenomics of microbial traits within oceanic viral communities. *Isme J* 5: 1178-1190. doi:10.1038/ismej.2011.2

Sharon, I. , Tzahor, S. , Williamson, S. , Shmoish, M. , Man-Aharonovich, D. , Rusch, D. B. , Yooseph, S. , Zeidner, G. , Golden, S. S. , Mackey, R. , Adir, N. , Weingart, U. , Horn, D. , Venter, J. C. , Mandel-Gutfreund, Y. , and Béjà, O. (2007) Viral photosynthetic reaction center genes and transcripts in the marine environment. *Isme J* 1: 492-501.

Shen, G. , Saunée, N. A. , Williams, S. R. , Gallo, E. F. , Schluchter, W. M. , and Bryant D. A. (2006) Identification and characterization of a new class of bilin lyase. The *cpcT* gene encodes a bilin lyase responsible for attachment of phycobilin to Cys-153 on the β -subunit of

phycocyanin in *Synechococcus* sp. PCC 7002. *J Biol Chem* 281: 17768-17778.

Sherman, L. A. (1976) Infection of *Synechococcus cedrorum* by cyanophage AS-1M. III. Cellular development and phage metabolism. *Virology* 71: 199-206.

Sherman, L. A. , and Connelly, M. (1976) Isolation and characterization of a cyanophage infecting the unicellular blue-green algae *Anacystis nidulans* and *Synechococcus cedrorum*. *Virology* 72: 540-544.

Sherman, L. A. , and Haselkorn, R. (1970a) LPP-1 infection of the blue-green alga *Plectonema boryanum*. I. Electron microscopy. *J Virol* 6: 820-833.

Sherman, L. A. , and Haselkorn, R. (1970b) LPP-1 infection of the blue-green alga *Plectonema boryanum*. II. Viral deoxyribonucleic acid synthesis and host deoxyribonucleic acid breakdown. *J Virol* 6: 834-840.

Sherman, L. A. , and Haselkorn, R. (1970c) LPP-1 infection of the blue-green alga *Plectonema boryanum*. III. Protein synthesis. *J Virol* 6: 841-846.

Sherman, L. A. , and Haselkorn, R. (1971) Growth of the blue-green algae virus LPP-1 under conditions which impair photosynthesis. *Virology* 45: 739-746.

Sherman, L. A. , and Pauw, P. (1976) Infection of *Synechococcus cedrorum* by AS-1M. II. Protein and DNA synthesis. *Virology* 71: 17-27.

Sherman, L. A. , Connelly, M. , and Sherman, D. (1976) Infection of *Synechococcus cedrorum* by the cyanophage AS-1M. 1. Ultrastructure of infection and phage assembly. *Virology* 71: 1-16.

Short, S. M. , and Suttle, C. A. (2000) Denaturing gradient gel electrophoresis resolves virus sequences amplified with degenerate primers. *BioTechniques* 28: 20-22.

Short, S. M. , and Suttle, C. A. (2002) Sequence analysis of marine virus communities reveals that groups of related algal viruses are widely distributed in nature. *Appl Environ Microbiol* 68: 1290-1296.

Short, S. M. , and Suttle, C. A. (2003) Temporal dynamics of natural communities of marine algal viruses and eukaryotes. *Aquat Microb Ecol* 32: 107-119.

Short, C. M. , and Suttle, C. A. (2005) Nearly identical bacteriophage structural gene sequences are widely distributed in both marine and freshwater environments. *Appl Environ Microbiol* 71: 480-486.

Sieburth, J. M. (1979) *Sea Microbes*. Oxford University Press, New York, NY, USA. 491 pp.

Sieburth, J. M. , Johnson, P. W. , and Hargraves, P. E. (1988) Ultrastructure and ecology of *Aureococcus anophagefferens* gen. et sp. nov. (Chrysophyceae) the dominant picoplankton during a bloom in Narragansett Bay, Rhode Island USA Summer. *J Phycol* 24: 416-425.

Singh, P. K. (1973) Occurrence and distribution of cyanophages in ponds, sewage and rice fields. *Arch Mikrobiol* 89: 169-172.

Singh, R. N. , and Chaubey, I. J. (1976) The genetics of cyanophyceae and cyanophages: problems and prospects. *J. Cytol. Genet.* 11: 116-121.

Singh, R. N. , and Kashyap, A. K. (1977) Isolation and characterization of temperature- sensitive mutants of cyanophage LPP-1. *Mol Gen Genet* 154: 31-34.

Singh, R. N. , and Singh, P. K. (1967) Isolation of cyanophages from India. *Nature (London)* 216: 1020-1021.

Singh, R. N. , and Singh, P. K. (1972) Transduction and lysogeny in blue-green algae. In: Desikachary, T. V. (Ed.) *Taxonomy and Biology of Blue-Green Algae*. University of Madras, Madras, India. pp. 258-262.

Singh, R. N. , Singh, P. K. , Kashyap, A. K. , Sarma, T. A. , Dhar, B. , Chaubey, I. J. , and Choudhury, I. D. (1972) Isolation and characterization of new cyanophages and mutations of LPP-1 and host alga *Plectonema boryanum*. In: Desikachary, T. V. (Ed) *Taxonomy and Biology of Blue-green Algae*, University of Madras, Madras. pp. 585-591.

Sirenko, L. A. , Myslovich, V. O. , Goryushin, V. A. , Mikhailyuk, D. P. (1976) Effect of infection with cyanophage AM-1 on the metabolism of the blue-green alga. *Fiziol. Rast.* 23: 1214-1218.

Smith, K. M. , Brown, Jr., R. M. , Goldstein, D. A. , and Walne, P.L. (1966) Culture methods for the blue-green alga *Plectonema boryanum* and its virus, with an electron microscope study of virus-infected cells. *Virology* 28: 580-591.

Sode, K. , Oonari, R. , and Oozeki, M. (1997) Induction of a temperate marine cyanophage by heavy metal. *J Mar Biotechnol* 5: 178-180.

Sode, K. , Oozeki, M. , Asakawa, K. , Burgess, J. G. , and Matsunaga, T. (1994) Isolation of marine cyanophages infecting the marine unicellular cyanobacterium *Synechococcus* sp. NKBG042902. *J Mar Biotechnol* 1: 189-192.

Stahl, D. A. , Lane, D. J. , Olsen, G. J. , and Pace, N. R. (1985) Characterization of a Yellowstone hot spring microbial community by 5S rRNA sequences. *Appl Environ Microbiol* 49: 1379-1384.

Stern, A. , and Sorek, R. (2011) The phage-host arms race: Shaping the evolution of microbes. *Bioessays*. 33: 43-51. doi:<https://doi.org/10.1002/bies.201000071>

Steward, G. F. , Smith, D. C. , and Azam, F. (1996) Abundance and production of bacteria and viruses in the Bering and Chukchi seas. *Mar Ecol Prog Ser* 131: 287-300.

Steward, G. F. , Winker, J. , Cochlan, W. P. , Smith, D. C. , and Azam, F. (1992a) Estimation of virus production in the sea. II. Field results. *Mar Microbial Food Webs* 6: 79-90.

Steward, G. F. , Winker, J. , Smith, D. C. , Cochlan, W. P. , and Azam, F. (1992b) Estimation of virus production in the sea. I. Method development. *Mar Microbial Food Webs* 6: 57-78.

Stoddard, L. I. , Martiny, J. B. , and Marston, M. F. (2007) Selection and characterization of cyanophage resistance in marine *Synechococcus* strains. *Appl Environ Microbiol* 73: 5516-5522.

Storrie-Lombardi, M. C. , and Pinkart, H. C. (2007) Co-evolution of cyanophage and cyanobacteria in Antarctic lakes: Adaptive responses to high UV flux and global warming. In: Hoover, R. B. , Levin, G. V. , and Rozanov, A. (Eds.) *Astrobiology and Planetary Missions*. X. SPIE, Bellingham, WA, USA. pp. 1-13

Sullivan, M. B. , Coleman, M. L. , Weigle, P. , Rohwer, F. , and Chisholm, S. W. (2005) Three *Prochlorococcus* cyanophage genomes: Signature features and ecological interpretations. *PLoS Biol* 3: e144 0790-0806. www.plosbiology.org

Sullivan, M. B. , Coleman, M. L. , Quinlivan, V. , Rosenkrantz, J. E. , DeFrancesco, A. S. , Tan, G. , Fu, R. , Lee, J. A. Waterbury, J. B. , Bielawski, J. P. , and Chisholm, S. W. (2008) Portal protein diversity and phage ecology. *Environ Microbiol* 10: 2810-2823. doi:<https://doi.org/10.1111/S.1462-2920.2008.02280.x>

Sullivan, M. B. , Huang, K. H. , Ignacio-Espinoza, J. C. , Berlin, A. M. , Kelly, L. , Weigle, P. R. , DeFrancesco, A. S. , Kern, S. E. , Thompson, L. R. , Young, S. , Yandava, C. , Fu, R. , Krastins, B. , Chase, M. , Sarracino, D. , Osburne, M. S. , Henn, M. R. , and Chisholm, S. W. (2010) Genome analysis of oceanic cyanobacterial myoviruses compared with T-4 like myoviruses from diverse hosts and environments. *Environ Microbiol* 12: 3035-3056. doi:<https://doi.org/10.1111/j.1462-2920.2010.02280.x>

Sullivan, M. B. , Krastins, B. , Hughes, J. L. , Kelly, L. , Chase, M. , Sarracino, D. , and Chishom, S. W. (2009) The genome and structural proteome of an ocean siphovirus: A new window into the cyanobacterial "mobilome". *Environ Microbiol* 11: 2935-2951. doi: 1111/j.1462-2920.2009.02081.x

Sullivan, M. B. , Lindell, L. , Lee, J.A. , Thompson, L. R. , Bielawski, J. P. , and Chisholm, S. W. (2006) Prevalence and evolution of core photosystem II genes in marine cyanobacterial viruses and their hosts. *PLoS Biol* 4: e234. www.plosbiology.org

Sullivan, M. B. , Waterbury, J. B. , and Chisholm, S. W. (2003) Cyanophages infecting the oceanic cyanobacterium *Prochlorococcus*. *Nature (London)* 424: 1047-1050.

Suttle, C. A. (1993) Enumeration and isolation of virus. In: Kemp, P. F. , Sherr, B. F. , Sherr, E. B. , and Cole, J. J. . (Eds.) *Handbook of Methods in Aquatic Microbial Ecology* 28: 237-243.

Suttle, C. A. (2000) Cyanophages and their role in the ecology of cyanobacteria. In: Whitton, B. A. , and Potts, M. . (Eds.) *The Ecology of Cyanobacteria*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 563-589.

Suttle, C. A. (2005) Viruses in the sea. *Nature (London)* 437: 356-361.

Suttle, C. A. , and Chan, A. M. (1993) Marine cyanophages infecting oceanic and coastal strains of *Synechococcus*: Abundance, morphology, cross-infectivity and growth characteristics. *Mar Ecol Prog Ser* 92: 99-109.

Suttle, C. A. , and Chan, A. M. (1994) Dynamics and distribution of cyanophages and their effect on marine *Synechococcus* spp. *Appl Environ Microbiol* 60: 3167-3174.

Suttle, C. A. , and Chen, F. (1992) Mechanisms and rates of decay of marine viruses in seawater. *Appl Environ Microbiol* 58: 3721-3729.

Suttle, C. A. , Chan, A. M. , and Cottrell, M. T. (1990) Infection of phytoplankton by viruses and reduction of primary productivity. *Nature (London)* 347: 467-469.

Suttle, C. A. , Chan, A. M. , and Cottrell, M. T. (1991) Use of ultrafiltration to isolate viruses from seawater which are pathogens of marine phytoplankton. *Appl Environ Microbiol* 57: 721-726.

Szekers, M. (1981) Phage induced development of site specific endonuclease in *Anacystis nidulans*, a cyanobacterium. *Virology* 111: 1-10.

Szekers, M. , Szmidt, A. E. , and Torok, I. (1983) Evidence for restriction modification-like system in *Anacystis nidulans* infected by cyanophage AS-1. *Eur J Biochem* 131: 137-141.

Takashima, Y. , Yoshida, T. , Yoshida, M. , Shirai, Y. , Tomaru, Y. , Takao, Y. , Hiroishi, S. , and Nagasaki, K. (2007) Development and application of quantitative detection of cyanophages phylogenetically related to cyanophages Ma-LMM01 infecting *Microcystis aeruginosa* in freshwater. *Microbes Environ* 22: 207-213.

Teklemariam, T. A. , Demeter, S. , Dea, Z. , Suranyi, G. , and Borbely, G. (1990) AS-1 cyanophage infection inhibits the photosynthetic electron flow of photosystem II in *Synechococcus* sp. PCC 6301, a cyanobacterium. *FEBS Lett* 270: 211-215.

Tétart, F. , Desplats, C. , Kutateladze, M. , Monod, C. , Ackermann, H-W. , and Krisch, H. M. (2001) Phylogeny of the major head and tail genes of the wide-ranging T4 bacteriophages. *J Bacteriol* 183: 358-366.

Thingstad, T. F. , and Lignell, R. (1997) A theoretical approach to the question of how trophic interactions control carbon demand, growth rate, abundance and diversity. *Aquat Microb Ecol* 13:19-27.

Ting, C.S. , Rocap, G. , King, J. , and Chisholm, S.W. (2002) Cyanobacterial photosynthesis in the oceans: The origins and significance of divergent light-harvesting strategies. *Trends Microbiol* 10: 134-142.

Torrella, F. , and Morita, R. Y. (1979) Evidence by electron micrographs for a high incidence of bacteriophage particles in the waters of Yaquina Bay, Oregon: Ecological and taxonomical implications. *Appl Environ Microbiol* 37: 774-778.

Trivedi, J. P. , and Oza, P. P. (1979) A lytic agent for blue-green alga *Oscillatoria chlorina* from cooling towers. *Comp Physiol Ecol* 4: 207-212.

Tucker, S. , and Pollard, P. (2005) Identification of cyanophages Ma-LBP and infection of the cyanobacterium *Microcystis aeruginosa* from an Australian subtropical Lake by the virus. *Appl Environ Microbiol* 71: 629-655.

Twort, F.W. (1915) An investigation on the nature of ultra-microscopic viruses. *Lancet* ii: 1241-1243.

van Boekel, W. H. M. , Hansen, F. C. , Riegman, R. , and Bak, R. P. M. (1992) Lysis-induced decline of a *Phaeocystis* spring bloom coupling with the microbial food web. *Mar Ecol Prog Ser* 81: 269-276.

Venkataraman, G. S. , Kaushik, B. D. , Subramanian, G. , Shanmugasundaram, G. , and Govindarajan, A. (1973) Cyanophage AC-1: A phage infecting unicellular and colonial blue-green algae. *Curr Sci* 42: 104-105.

Venter, J. C. , Remington, K. , Heidelberg, J. , Halpern, A. L. , Rusch, D. , and Eisen, J. A. (2004) Environmental genome shotgun sequencing of the Sargasso Sea. *Science* 304: 66-74.

Vrede, K. , Stensdotter, U. , and Lindstrom, E. (2003) Viral and bacterioplankton dynamics in two lakes with different humic contents. *Microb Ecol* 46: 406-415.

Wang, G. , Murase, J. , Asakawa, S. , and Kimura, M. (2010) Unique viral capsid assembly protein gene (g20) of cyanophages in the floodwater of a Japanese paddy field. *Biol Fertil Soils* 46: 93-102. doi:<https://doi.org/10.1007/s00374-009-0410-y>.

Wang, K. , and Chen, F. (2004) Genetic diversity and population dynamics of cyanophage communities in the Chesapeake Bay. *Aquat Microb Ecol* 34: 105-116.

Wang, K. , and Chen, F. (2008) Prevalence of highly host-specific cyanophages in the estuarine environment. *Environ Microbiol* 10: 300-312.

Waterbury, J. B. , and Rippka, R. M. (1989) Subsection I. Order Chroococcales Wettstein 1924, emend. Rippka et al., 1979, p. 1728-1729. In: Krieg, N. R. , and Holt, J. B. (Eds.) *Bergey's Manual of Systematic Bacteriology*. Vol. 3. Williams and Wilkins, Baltimore, USA.

Waterbury, J. B. , and Valois, F. W. (1993) Resistance to co-occurring phages enables marine *Synechococcus* communities to coexist with cyanophages abundant in seawater. *Appl Environ Microbiol* 59: 3393-3399.

Waterbury, J. B. , Watson, S. W. , Guillard, R. R. L. , and Brand, L. E. (1979) Widespread occurrence of a unicellular marine planktonic cyanobacterium. *Nature (London)* 277: 293-294.

Waterbury, J. B. , Watson, S. W. , Valois, F. W. , and Franks, D. G. (1986) Biological and ecological characterization of the marine unicellular cyanobacterium *Synechococcus*. *Can Bull Fish Aquat Sci* 214: 71-120.

Weigle, P. R. , Pope, W. H. , Pedulla, M. L. , Houtz, J. M. , Smith, A. L. , Conway, J. F. , King, J. , Hatfull, G. F. , Lawrence, J. G. , and Hendrix, R. W. (2007) Genomic and structural analysis of Syn9, a cyanophage infecting marine *Prochlorococcus* and *Synechococcus*. *Environ Microbiol* 9: 1675-1695.

Weinbauer, M. G. , Wilhelm, S. W. , Suttle, C. A. , Pledger, R. J. , and Mitchell, D. L. (1999) Sunlight-induced DNA damage and resistance in natural viral communities. *Aquat Microb Ecol* 17: 111-120.

Wen, K. , Ortamnn, A. C. , and Suttle, C. A. (2004) Accurate estimation of viral abundance by epifluorescence microscopy. *Appl Environ Microbiol* 70: 3862-3867.

Wharam, S. D. , Hall, M. J. , and Wilson, W. H. (2007) Detection of virus mRNA within infected host cells using an isothermal nucleic acid amplification assay: Marine cyanophage gene expression within *Synechococcus* sp. *Virology J* 4: 52 doi:<https://doi.org/10.1186/1743-422X-4-52>

Wilcox, R. M. , and Fuhrman, J. A. (1994) Bacterial viruses in coastal seawater: Lytic rather than lysogenic production. *Mar Ecol Prog Ser* 114: 35-45.

Wilhelm, S. W. , and Suttle, C. A. (1999) Viruses and nutrient cycles in the sea. *BioScience* 49: 781-788.

Wilhelm, S. W. , Carberry, M. J. , Eldridge, M. L. , Poorvin, L. , Saxton, M. A. , and Doblin, M. A. (2006) Marine and freshwater cyanophages in a Laurentian Great Lake: Evidence from infectivity assays and molecular analyses of g20 genes. *Appl Environ Microbiol* 72: 4957-4963.

Williamson, K. E. , Wommack, K. E. , and Rodosevich, M. (2003) Sampling natural viral communities from soil for culture- independent analyses. *Appl Environ Microbiol* 69: 6628-6633.

Williamson, S. J. , Rusch, D. B. , Yooseph, S. , Halpern, A. L. , Heidelberg, K. B. , Glass, J. I. , Andrews-Pfannkoch, C. , Fadrosh, D. , Miller, C. S. , Sutton, G. , Frazier, M. , and Venter, J. C. (2008) The Sorcerer II Global Ocean Sampling expedition: Metagenomic characterization of viruses within aquatic microbial samples. *PLoS ONE* 3: e1456. doi:<https://doi.org/10.1371/journal.pone.0001456>.

Wilson, W. H. (1994) Characterization of viruses which infect marine phytoplankton. Ph.D. thesis. University of Warwick, Coventry, United Kingdom.

Wilson, W. H. , Carr, N. G. , and Mann, N. H. (1996) The effect of phosphate status on the kinetics of cyanophage infection in the Oceanic cyanobacterium *Synechococcus* sp. WH 7803. *J Phycol* 32: 506-516.

Wilson, W. H. , Joint, I. R. , Carr, N. G. , and Mann, N. H. (1993) Isolation and molecular characterization of five marine cyanophages propagated on *Synechococcus* sp. strain WH 7803. *Appl Environ Microbiol* 59: 3736-3743.

Wilson, W. H. , Nicholas, J. F. , Joint, I. R. , and Mann, N. H. (1999) Analysis of cyanophage diversity and population structure in a south-north transect of the Atlantic Ocean. *Bull Inst Oceanogr (Monaco)* 19: 209-226.

Wilson, W. H. , Nicholas, J. F. , Joint, I. R. , and Mann, N. H. (2000) Analysis of cyanophage diversity in the marine environment using denaturing gradient gel electrophoresis. In: Bell, C. R. , Bryliksky, M. , and Johnson-Green, P. (Eds.) *Microbial Biosystems: a New Frontier*. Proc 8th Intl Symp on Microbial Ecology, Halifax, Nova Scotia, Canada. pp. 565-570.

Wilson, W. H. , Turner, S. , and Mann, N. H. (1998) Population dynamics of phytoplankton and viruses in a phosphate limited mesocosm and their effect on DMSP and DMS production. *Eстуarine Coastal Shelf Sci* 46: 49-59.

Wommack, K. E. , and Colwell, R. R. (2000) Virioplankton: Viruses in aquatic ecosystems. *Microbiol Mol Biol Rev* 64: 69-114.

Wommack, K. E. , Hill, R. T. , Kelle, M. , Russek-Cohen, E. , and Colwell, R. A. (1992) Distribution of viruses in the Chesapeake Bay. *Appl Environ Microbiol* 58: 2965-2970.

Wu, J. H. , Choules, G. L. , and Lewin, R. A. (1968) Early stage of the infection process in blue-green algal virus system, as affected by KCN and light. In: *Biochemical Regulation in Diseased Plants or Injury*. Photopathological Society of Japan, Tokyo. pp. 153-160.

Yoshida, M. , Yoshida, T. , Takashima, Y. , Kondo, R. , and Hiroishi, S. (2005) Genetic diversity of the toxic cyanobacterium *Microcystis* in Lake Mikata. *Environ Toxicol* 20: 229-234.

Yoshida, M. , Yoshida, T. , Takashima, Y. , Hosoda, N. , and Hiroishi, S. (2007) Dynamics of microcystin-producing and non- microcystin-producing *Microcystis* population is correlated with nitrate concentration in a Japanese Lake. *FEMS Microbiol Lett* 266: 49-53.

Yoshida, M. , Yoshida, T. , Kashima, A. , Takashima, Y. , Hosoda, N. , Nagasaki, K. , and Hiroishi, S. (2008) Ecological dynamics of the toxic bloom-forming cyanobacterium *Microcystis aeruginosa* and its cyanophages in freshwater. *Appl Environ Microbiol* 74: 3269-3273.

Yoshida, M. , Yoshida, T. , Yoshida-Takashima, Y. , Kashima, A. , and Hiroishi, S. (2010) Real-time PCR detection of host- mediated cyanophage gene transcripts during infection of a natural *Microcystis aeruginosa* population. *Microbes Environ* 25: 211-215. doi:<https://doi.org/10.1264/jsme2-ME10117>

Yoshida, T. , Nagasaki, K. , Takashima, Y. , Shirai, Y. , Tomaru, Y. , Takao, Y. , Sakamoto, S. , Hiroishi, S. , and Ogata, H. (2008) Ma-LMM01 infecting toxic *Microcystis aeruginosa* illuminates diverse cyanophages genome strategies. *J Bacteriol* 190: 1762-1772.

Yoshida, T. , Takashima, Y. , Tomaru, Y. , Shirai, Y. , Takao, Y. , Hiroishi, S. , and Nagasaki, K. (2006) Isolation and characterization of a cyanophage infecting the toxic cyanobacterium *Microcystis aeruginosa*. *Appl Environ Microbiol* 72: 1239-1247.

Zeidner, G. , Bielawski, J. P. , Shmoish, M. , Scanlan, D. J. , Sabehi, G. , and B  j  , O. (2005) Potential photosynthesis gene recombination between *Prochlorococcus* and *Synechococcus* via viral intermediates. *Environ Microbiol* 7: 1505-1513.

Zhong, Y. , Chen, F. , Wilhelm, S. W. , Poorvin, L. , and Hodson, R. E. (2002) Phylogenetic diversity of marine cyanophage isolates and natural virus communities as revealed by sequences of viral capsid assembly protein g20. *Appl Environ Microbiol* 68: 1576-1584.

Zinger, L. , Gobet, A. , and Pommiers, T. (2011) Two decades of describing unseen majority of aquatic microbial diversity. *Mol Ecol* doi:<https://doi.org/10.1111/j.1365.294x.2011.05362.x>

Cyanobacterial Toxins

Aas, P. , Eriksen, S. , Kolderup, J. , Lundy, P. , Haugen, J.-E. , Skulberg, O. M. , and Fonnum, F. (1996) Enhancement of acetylcholine release by homoanatoxin-a from *Oscillatoria formosa*. *Environ Toxicol Pharmacol* 2: 223-232.

Adelman, W. J. , Fohlmeister, J. F. , Sasner, J. J. , and Ikawa, M. (1982) Sodium channels blocked by aphanotoxin obtained from the blue-green alga *Aphanizomenon flos-aquae*. *Toxicon* 20: 513-516.

Adeyemo, O. M. , and Siren, A.-L. (1992) Cardiorespiratory changes and mortality in the conscious rat induced by (+) and (  )-anatoxin-a. *Toxicon* 30: 899-905.

Agrawal, M. K. , Bagchi, D. , and Bagchi, S. N. (2001) Acute inhibition of protease and suppression of growth in zooplankter, *Monia macrocopa*, by *Microcystis* blooms collected in Central India. *Hydrobiologia* 464: 37-44.

Akcaalan, R. , Young, F. M. , Metcalf, J. S. , Morrison, L. F. , Albay, M. , and Codd, G. A. (2006) Microcystin analysis in single filaments of *Planktothrix* spp. in laboratory cultures and environmental samples. *Water Res* 40: 1583-1590.

Akin-Oriola, G. A. , and Lawton, L. A. (2005) Detection and quantification of toxins in cultures of *Microcystis aeruginosa* (PCC 7820) by HPLC and protein phosphatase inhibition assay effect of blending various collectors at bulk. *Afr J Sci Technol* 6: 1-10.

- Alam, M. , Ikawa, M. , Sasner, J. J. , Jr. , and Sawyer, P. J. (1973) Purification of Aphanizomenon flos-aquae toxin and its chemical and physiological properties. *Toxicon* 11: 65–72.
- Albay, M. , Akcaalan, R. , Tufekci, H. , Metcalf, J. S. , Beattie, K. A. , and Codd, G. A. (2003) Depth profiles of cyanobacterial hepatotoxins (microcystins) in three Turkish freshwater lakes. *Hydrobiologia* 505: 89–95.
- Albay, M. , Matthiensen, A. , and Codd, G. A. (2005) Occurrence of toxic blue-green algae in the Kuckcekmece lagoon (Istanbul, Turkey). *Environ Toxicol* 20: 277–284.
- Allender, C. J. , LeClerc, G. R. , Rinta-Kanto, J. M. , Small, R. L. , Stachwell, M. F. , Boyer, G. L. , and Wilhelm, S. W. (2009) Identifying the source of unknown microcystin genes and predicting microcystin variants by comparing genes with uncultured cyanobacterial cells. *Appl Environ Microbiol* 75: 3598–3604.
- Al-Tebrineh, J. , Mihali, T. K. , Pomati, T. and Neilan, B. A. (2010) Detection of saxitoxin-producing cyanobacteria and *Anabaena circinalis* in environmental water blooms by quantitative PCR. *Appl Environ Microbiol* 76: 7836–7842. doi:10.1128/AEM.00174-10
- Amorim, A. , and Vasconcelos, V. (1999) Dynamics of microcystins in the mussel *Mytilus galloprovincialis*. *Toxicon* 37: 1181–1185.
- An, J. , and Carmichael, W. W. (1994) Use of a colorimetric protein phosphatase inhibition assay and enzyme linked immunosorbent assay for the study of microcystins and nodularins. *Toxicon* 32: 1495–1507.
- Annala, A. , Lehtimaeki, J. , Manila, K. , Eriksson, J. E. , Sivonen, K. , Rantala, T. T. , and Drakenberg, T. (1996) Solution structure of nodularin an inhibitor of serine/threonine specific protein phosphatases. *J Biol Chem* 271: 16695–16702.
- Aráoz, R. , Nghiem, H.-O. , Rippka, R. , Palibroda, N. , Tandeau de Marsac, N. , and Herdman, M. (2005) Neurotoxins in axenic oscillatorian cyanobacteria: Coexistence of anatoxin-a and homoanatoxin-a determined by ligand-binding assay and GC/MS. *Microbiology* 151: 1263–1273.
- Aráoz, R. , Molgó, J. , and Tandeau de Marsac, N. (2010) Neurotoxic cyanobacterial toxins. *Toxicon* 56: 813–828. doi:10.1016/j.toxicon.2009.07.036
- Arment, A. R. , and Carmichael, W. W. (1996) Evidence that microcystin is a thiotemplate product. *J Phycol* 32: 591–597.
- Aronstam, R. S. , and Witkop, B. (1981) Anatoxin-a interactions with cholinergic synaptic molecules. *Proc Natl Acad Sci USA* 78: 4639–4643.
- Ash, C. , MacKintosh, C. , and MacKintosh, (1995) Use of a protein phosphatase inhibition test for the detection of cyanobacterial toxins in water. *Water Sci Technol* 31: 51–53.
- Astrachan, N. B. , Archer, B. G. , and Hilbelink, D. R. (1980) Evaluation of the sub-acute toxicity and teratogenicity of anatoxin-a. *Toxicon* 18: 684–688.
- Atkins, R. , Rose, T. , Brown, R. S. , and Robb, M. (2001) The Microcystis cyanobacteria bloom in the Swan River-February 2000. *Water Sci Technol* 43: 107–114.
- Atkondon, M. , and Abulquerque, E. X. (1995) Diversity of nicotinic acetylcholine receptors in rat hippocampal neurons. III. Agonist actions of the novel alkaloid epibatidine and analysis of type II current. *J Pharmacol Exp Ther* 274: 771–782.
- Azevedo, S. M. F. O. (1996) Current studies on toxic cyanobacteria in Brazil. *Reunião Anual da Federação de sociedades de Biologia Experimental*, 12 Caxambu, MG, 40p.
- Azevedo, S. M. F. O. , Evans, W. R. , Carmichael, W. W. , and Namikoshi, M. (1994) First report of Microcystis from a Brazilian isolate of the cyanobacterium Microcystis aeruginosa. *J Appl Phycol* 6: 261–265.
- Bagu, J. R. , Skyes, B. D. , Craig, M. M. , and Holmes, C. F. B. (1997) A molecular basis for different interactions of marine toxins with protein phosphatase-1. *J Biol Chem* 272: 5087–5097.
- Baker, P. (1992) *Anabaena circinalis*. In: Tyler, P. (Ed.) *Identification of Common Noxious Cyanobacteria*. Part I. Nostocales. Melbourne Water Corporation, Melbourne, Australia.
- Baker, P. D. , and Humpage, A. R. (1994) Toxicity associated with commonly occurring cyanobacteria in surface waters of Murray-Darling basin, Australia. *Aus J Mar Freshwat Res* 45: 773–786.
- Balasubramanian, G. , Dionysiou, D. D. , Suidan, M. T. , Subramanian, V. , Baudin, I. , and Laine, J. M. (2003) Titania powder modified sol-gel process for photocatalytic applications. *J Mat Sci* 38: 823.
- Ballot, A. , Fastner, J. , and Wiedner, C. (2010a) Paralytic shellfish poisoning toxin-producing cyanobacterium *Aphanizomenon gracile* in northeast Germany. *Appl Environ Microbiol* 76: 1173–1180. doi:10.1128/AEM.02285-09
- Ballot, A. , Fastner, J. , Lentz, M. , and Wiedner, C. (2010b) First report of anatoxin-a producing cyanobacterium *Aphanizomenon issatschenkoi* in northeastern Germany. *Toxicon* 56: 964–971.
- Banker, R. , Carmeli, S. , and Hadas, O. (1997) Identification of cylindrospermopsin in *Aphanizomenon ovalisporum* (Cyanophyceae) isolated from Lake Kinneret, Israel. *J Phycol* 33: 613–616.
- Banker, R. , Carmeli, S. , Werman, M. , Teltsch, B. , Porat, R. , and Sukenik, A. (2001) Uracil moiety is required for toxicity of the cyanobacterial hepatotoxin cylindrospermopsin. *J Toxicol Environ Health* 62: 281–288.
- Banker, R. , Teltsch, B. , Sukenik, A. , and Carmeli, S. (2000) 7-Epicylindrospermopsin, a toxic minor metabolite of the cyanobacterium *Aphanizomenon ovalisporum* from lake Kinneret, Israel. *J Nat Prod* 63: 387–389.
- Barford, D. , and Keller, J. (1994) Co-crystallization of the catalytic subunit of the serine/threonine specific protein phosphatase 1 from human in complex with microcystin-LR. *J Mol Biol* 235: 763–766.
- Bateman, K. P. , Thibault, P. , Douglas, D. J. , and White, R. L. (1995) Mass spectral analyses of microcystins from toxic cyanobacteria using on-line chromatographic and electrophoretic separations. *J Chromatogr* 712: 253–268.
- Bauer, C. , Scappino, L. , and Haselkorn, R. (1993) Growth of the cyanobacterium *Anabaena* on molecular nitrogen: NifJ is required when iron is limited. *Proc Natl Acad Sci USA* 90: 8812–8816.
- Beasley, V. R. , Lovell, R. A. , Holmes, K. R. , Walcott, H. E. , Schaeffer, D. J. , Hoffman, W. E. , and Carmichael, W. W. (2000) Microcystin-LR decreases hepatic and renal perfusion, and causes circulatory shock, severe hypoglycemia, and terminal hyperkalemia in intravascular dosed swine. *J Toxicol Environ Health* 61: 281–303.
- Beattie, K. A. , Kaya, K. , and Codd, G. A. (2000) The cyanobacterium *Nodularia* PCC 7804, of freshwater origin, produces [L-Har2] nodularin. *Phytochemistry* 54: 57–61.
- Beattie, K. A. , Kaya, K. , Sano, T. , and Codd, G. A. (1998) Three dehydrobutyryne (Dhb)-containing microcystins from the cyanobacterium *Nostoc* sp. *Phytochemistry* 47: 1289–1292.
- Becker, S. , Boeger, P. , Oehlmann, R. , and Ernst, A. (2000) PCR bias in ecological analysis: A case study for quantitative Taq nuclease assays in analyses of microbial communities. *Appl Environ Microbiol* 66: 4486–4494.

Belknap, W. R. , and Haselkorn, R. (1987) Cloning and light regulation of expression of the phycocyanin operon of the cyanobacterium *Anabaena*. *Embo J* 6: 871–884.

Bell, S. G. , and Codd, G. A. (1996) Detection, analysis and risk assessment of cyanobacterial toxins. In: Hester, R. E. , and Harrison, R. M. (Eds.) *Agricultural Chemicals and the Environment. Issues in Environmental Science and Technology*. No. 5. Royal Society of Chemistry, Cambridge, UK. pp. 109–122.

Benndorf, J. , and Henning, M. (1989) *Daphnia* and toxic blooms of *Microcystis aeruginosa* in Bautzen reservoir (GDR). *Int Rev Hydrobiol* 74: 233–248.

Berman, F. W. , Gerwick, W. H. , and Murray, T. F. (1999) Antillatoxin and kalkitoxin, ichthyotoxins from the tropical cyanobacterium *Lyngbya majuscula*, induce distinct temporal patterns of NMDA receptor-mediated neurotoxicity. *Toxicon* 37: 1645–1648.

Bernard, C. , Harvey, M. , Briand, J. F. , Bire, R. , Krys, S. , and Fontaine, J. J. (2003) Toxicological comparison of diverse *Cylindrospermopsis raciborskii* strains: Evidence of liver damage caused by a French *C. raciborskii* strain. *Environ Toxicol* 18: 176–186.

Bernazeau, F. (1994) Can microcystins enter drinking water distribution systems? In: Steffensen, D. , and Nicholson, B. (Eds.) *Toxic Cyanobacteria. Current Status and Research Management*. American Water Works Association Research Foundation, Denver, CO, USA. pp. 115–118.

Best, J. H. , Eddy, F. B. , and Codd, G.A. (2003) Effects of *Microcystis* cells, cell extracts and lipopolysaccharide on drinking and liver function in rainbow trout *Oncorhynchus mykiss* Walbaum. *Aquat Toxicol* 64: 419–426.

Bickel, H. , and Lyck, S. (2001) Importance of energy change for microcystin production. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes, Consequences*. Springer Verlag, KG, Berlin. pp. 133–141.

Bittencourt-Oliveira, M. C. (2003) Detection of potential microcystin-producing cyanobacteria in Brazilian reservoirs with *mcyB* molecular marker. *Harmful Algae* 2: 51–60.

Bittencourt-Oliveira, M. C. , Oliveira, M. C. , and Bolch, C. J. S. (2001) Genetic variability of some Brazilian strains of *Microcystis aeruginosa* complex (Cyanophyceae/Cyanobacteria) using the nucleotide sequence analysis of the intergenic spacer and flanking regions from *cpcBA*-phycocyanin operon. *J Phycol* 37: 810–818.

Blaha, L. , Kopp, R. , Simkova, K. , and Mares, J. (2004) Oxidative stress biomarkers are modulated in silver carp (*Hypophthalmichthys molitrix* Val.) exposed to microcystin-producing cyanobacterial water bloom. *Acta Vet Brno* 73: 477–482.

Blom, J. F. , Robinson, J. A. , and Juettner, F. (2001) Higher grazer toxicity of [D-Asp3, (E)-Dhb7]microcystin-RR of *Planktothrix rubescens* as compared to different microcystins. *Toxicon* 39: 1923–1932.

Boe, R. , Gjersten, B. T. , Vintermyr, O. K. , Houge, G. , Lanotte, M. , and Doskeland, S. O. (1991) The protein phosphatase inhibitor okadaic acid induces morphological changes typical of apoptosis in mammalian cells. *Exptl Cell Res* 195: 237–246.

Boettcher, G. , Chorus, I. , Ewald, S. , Hintze, T. , and Walz, N. (2001) Light limited growth and microcystin content of *Planktothrix agardhii* and *Microcystis aeruginosa* in turbidostats. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes, Consequences*. Springer Verlag, KG, Berlin, Germany, pp. 115–133.

Boland, M. P. , Smillie, Chen, D. Z. X. , and Holmes, C. F. B. (1993) A unified bioscreen for the detection of diarrhetic shellfish toxins and microcystins in marine and freshwater environments. *Toxicon* 31: 1393–1405.

Botes, D. P. , Tuinman, A. A. , Wessels, P. L. , Viljoen, C. C. , Kruger, H. , Williams, D. H. , Santikarn, S. , Smith, R. J. , and Hammond, S. J. (1984) The structure of cyanoginosins-LA, a cyclic heptapeptide toxin from the cyanobacterium *Microcystis aeruginosa*. *J Chem Soc Perkin Trans I*: 2311–2318.

Botes, D. P. , Wessels, P. L. , Kruger, H. , Runnegar, M. T. C. , Santikarn, S. , Smith, R. J. , Barna, J. C. J. , and Williams, D. H. (1985) Structural studies on cyanoginosins-LR, -YR, -YA, and -M, peptide toxins from *Microcystis aeruginosa*. *J Chem Soc Perkin Trans 1*: 2747–2748.

Bouaicha, N. , and Nasri, A.-B. (2004) First report of cyanobacterium *Cylindrospermopsis raciborskii* from Algerian waters. *Environ Toxicol* 19: 541–543.

Bouaicha, N. , Rivasseau, C. , Hennion, M. C. , and Sandra, P. (1996) Detection of cyanobacterial toxins (microcystins) in cell extracts by micellar electrokinetic chromatography. *J Chromatogr* 685: 53–57.

Bourgoyne, D. L. , Hemscheidt, T. K. , Moore, R. E. , and Runnegar, M. T. C. (2000) Biosynthesis of cylindrospermopsin. *J Org Chem* 65: 152–156.

Bourke, A. T. C. , Hawes, R. B. , Neilan, A. , and Stallman, N. D. (1983) An outbreak of hepato-enteritis (the Palm Island mystery disease) possibly caused by algal intoxication. *Toxicon* 3: 45–48.

Bourne, D. G. , Blakeley, R. L. , Riddles, P. , and Jones, G. J. (2005) Development of polymerase chain reaction and fluorescent in situ hybridization techniques for the detection of a bacterial strain that degrades the cyanobacterial toxin microcystin LR. *Mar Freshwater Res* 56: 1127–1135.

Bourne, D. G. , Jones, G. J. , Blakeley, R. L. , Jones, A. , Negri, A. P. , and Riddles, P. (1996) Enzymatic pathway for the bacterial degradation of the cyanobacterial cyclic peptide toxin microcystin LR. *Appl Environ Microbiol* 62: 4086–4094.

Bourne, D. G. , Riddles, P. , Jones, G. J. , Smith, W. , and Blakeley, R. L. (2001) Characterization of a gene cluster involved in bacterial degradation of the cyanobacterial toxin microcystin-LR. *Environ Toxicol* 16: 523–534.

Boutwell, R. K. (1974) The function and mechanism of promoters in carcinogenesis. *CRC Crit Rev Toxicol* 2: 419–443.

Bouvy, M. , Falcao, D. , Marinho, M. , Pagano, M. , and Moura, A. (2000) Occurrence of *Cylindrospermopsis* (Cyanobacteria) in 39 Brazilian tropical reservoirs during the 1998 drought. *Aquat Microb Ecol* 23: 13–27.

Bouvy, M. , Molica, R. , Oliveira, S. , Marinho, M. , and Beker, B. (1999) Dynamics of a toxic cyanobacterial bloom (*Cylindrospermopsis raciborskii*) in a shallow reservoir in the semi-arid region of Northeast Brazil. *Aquatic Microb Ecol* 20: 285–297.

Briand, E. , Gugger, M. , Francois, J. C. , Bernard, C. , Humbert, J. F. , and Quiblier, C. (2008) Temporal variations in the dynamics of potentially microcystin-producing strains in a bloom-forming *Planktothrix agardhii* (cyanobacterium) population. *Appl Environ Microbiol* 74: 3839–3848.

Briand, J.-F. , Jacquet, S. , Bernard, C. , and Humbert, J. F. (2003) Health hazards for terrestrial vertebrates from toxic cyanobacteria in surface water ecosystems. *Vet Res* 34: 361–377.

Briand, J. F. , Jacquet, S. , Flinois, C. , Avois-Jacquet, C. , Maissonnette, C. , Leberre, B. , and Humbert, J. F. (2005) Variations in the microcystin production of *Planktothrix rubescens* (cyanobacteria) assessed from a four-year survey of Lac du Bourget (France) and from laboratory experiments. *Microb Ecol* 50: 418–428.

Brittain, S. , Mohamed, Z. A. , Wang, J. , Lehmann, V. K. B. , Carmichael, W. W. , and Rinehart, K. L. (2000) Isolation and characterization of microcystins from a River Nile strain of *Oscillatoria tenuis* Agardh ex Gomont. *Toxicon* 38: 1759–1771.

Brooks, W. P. , and Codd, G. A. (1987) Distribution of *Microcystis aeruginosa* peptide toxin and interactions with hepatic microsomes in mice. *Pharmacol Toxicol* 60: 187–191.

Brooks, W. P. , and Codd, G. A. (1988) Immunoassay of hepatotoxic cultures and water blooms of cyanobacteria using *Microcystis aeruginosa* peptide toxin polyclonal antibodies. *Environ Technol Lett* 9: 1343–1348.

Bruno, M. , Barbini, D. A. , Pierdominici, E. , Serse, A. P. , and Ioppolo, A. (1994) Anatoxin-a and a previously unknown toxin in *Anabaena planctonica* from blooms found in lake Mulargia (Italy). *Toxicon* 32: 369–373.

Bumke-Vogt, C. , Mailahn, W. , and Chorus, I. (1999) Anatoxin-a and neurotoxic cyanobacteria in German lakes and reservoirs. *Environ Toxicol* 14: 117–125.

Burgoyne, D. L. , Hemscheidt, T. K. , Moore, R. E. , and Runnegar, M. T. (2000) Biosynthesis of cylindrospermopsin. *J Org Chem* 65: 152–156.

Burke, W. A. , and Tester, P. A. (2002) Skin problems related to non-infectious coastal organisms. *Dermatologic Therapy* 15: 10–17.

Byth, S. (1980) Palm Island mystery disease. *Med J Aus* 2: 40–42.

Cadel-Six, S. , Dauga, C. , Castets, A. M. , Rippka, R. , Bouchier, C. , Tandeau de Marsac, N. , and Welker, M. (2008) Halogenase genes in non-ribosomal peptide synthetase gene clusters of *Microcystis* (cyanobacteria): Sporadic distribution and evolution. *Mol Biol Evol* 25: 2031–2041.

Cadel-Six, S. , Peyraud-Thomas, C. , Brient, L. , Tandeau de Marsac, N. , Rippka, R. , and Méjean, A. (2007) Different genotypes of anatoxin-producing cyanobacteria coexist in Tarn River, France. *Appl Environ Microbiol* 73: 7605–7614.

Campbell, D. L. , Lawton, L. A. , Beattie, K. A. , and Codd, G. A. (1994) Comparative assessment of the specificity of the brine shrimp and Microtox assays to hepatotoxic (microcystin-LR containing) cyanobacteria. *Environ Toxicol Water Qual* 9: 71–77.

Campos, V. , Cantarero, S. , Urrutia, H. , Heinze, R. , Wirsing, B. , Neumann, U. , and Weckesser, J. (1999) Microcystin in cyanobacterial blooms in Chilean lake. *Syst Appl Microbiol* 22: 169–173.

Cardellina, J. H., II , Moore, R. E. , Arnold, E. V. , and Clardy, J. (1979) Structure and absolute configuration of malyngolide, an antibiotic from the marine blue-green alga *Lyngbya majuscula* Gomont. *J Org Chem* 44: 4039–4042.

Carmichael, W. W. (1986) Algal toxins. In: Callow, J. A. (Ed.) *Advances in Botanical Research*. Academic Press, London, UK. pp. 47–101.

Carmichael, W. W. (1988) Toxins of freshwater algae. In: Tu, A. T. (Ed.) *Marine Toxins and Venoms, Handbook of Natural Toxins*. Marcel Dekker, New York, NY, USA. pp. 121–147.

Carmichael, W. W. (1992) Cyanobacteria secondary metabolites-the cyanotoxins. *J Appl Bacteriol* 72: 460–466.

Carmichael, W. W. (1994) The toxins of cyanobacteria. *Scientific American* 170: 78–86.

Carmichael, W. W. (1997) The cyanotoxins. In: Callow, J. (Ed.) *Advances in Botanical Research*, Vol. 27, Academic Press, London, UK pp. 211–256.

Carmichael, W. W. (2001) Health effects of toxin-producing cyanobacteria: “The cyanoHABs”. *Human and Ecological Risk Assessment* 7: 1393–1407.

Carmichael, W. W. , and Falconer, I. R. (1993) Disease related to freshwater algal blooms. In: Callow, J. A. (Ed.) *Advances in Botanical Research*, Academic Press, London, UK. pp. 187–210.

Carmichael, W. W. , and Li, R. H. (2006) Cyanobacteria toxins in the Salton Sea. *Saline Systems* 2: 5. doi: 10.1186/1746-1448-2-5

Carmichael, W. W. , Biggs, D. , and German, P. (1975) Toxicology and pharmacological action of *Anabaena flos-aquae* toxin. *Science* 187: 542–544.

Carmichael, W. W. , Biggs, D. , and Petterson, M. A. (1979) Pharmacology of anatoxin-a, produced by freshwater cyanophyte *Anabaena flos-aquae* NRC-44-1. *Toxicon* 17: 229–236.

Carmichael, W. W. , Azevedo, S. M. F. O. , An, J. S. , Molica, R. J. R. , Jochimsen, E. M. , Lau, S. , Rinehart, K. L. , Shaw, G. R. , and Eaglesham, G. K. (2001) Human fatalities from cyanobacteria: Chemical and biological evidence for cyanotoxins. *Environ Health Perspect* 109: 663–668.

Carmichael, W. W. , Beasley, V. R. , Bunner, D. L. , Eloff, J. N. , Falconer, I. R. , Gorham, P. , Harada, K. I. , Krishnamurthy, T. , Yu, M. J. , Moore, R. , Rinehart, K. , Runnegar, M. , Skulberg, O. M. , and Watanabe, M. (1988a) Naming of cyclic heptapeptide toxins of cyanobacteria (blue-green algae). *Toxicon* 26: 971–973.

Carmichael, W. W. , Eschedor, J. T. , Patterson, G. M. L. , and Moore, R. E. (1988b) Toxicity and partial structure of a hepatotoxic peptide produced by the cyanobacterium *Nodularia spumigena* Mertens emend L575 from New Zealand. *Appl Environ Microbiol* 54: 2257–2263.

Carmichael, W. W. , Evans, W. R. , Yin, Q. Q. , Bell, P. , and Moczydlowski, E. (1997) Evidence of paralytic shellfish poisons in the freshwater cyanobacterium *Lyngbya wollei* (Farlow ex Gomont) comb. nov. *Appl Environ Microbiol* 63: 3104–3110.

Carmichael, W. W. , Mahmood, N. A. , and Hyde, E. G. (1990) Marine toxins: Origins, structure and molecular pharmacology. In: Hall, S. , and Strichartz, G. (Eds.) *Natural Toxins from Cyanobacteria (Blue-Green Algae)*. American Chemical Society, Washington, DC, USA. pp. 87–106.

Carneiro, R. L. , Elisângela, M. , dos Santos, V. , Furlanetto Pacheco, A. B. , and de Oliveira e Azevedo, S. M. F. (2009) Effects of light intensity and light quality on growth and circadian rhythm of STX production in *Cylindrospermopsis raciborskii* (cyanobacteria). *J Plankton Res* 31: 481–488.

Catterall, W. A. , Morrow, G. S. , and Hartshame, R. P. (1979) Neurotoxin binding to receptor sites associated with the voltage sensitive sodium channels in intact, lysed, and detergent solubilized brain membranes. *J Biol Chem* 254: 11379–11387.

Cestele, S. , and Catterall, W. A. (2000) Molecular mechanisms of neurotoxin action on voltage-gated sodium channels. *Biochemie* 82: 883–892.

Chaivimol, J. , Swoboda, U. K. , and Dow, C. S. (1994) In: Codd, G. A. , Jefferies, T. M. , Keevil, C. W. , and Potter E. (Eds.) *Detection Methods for Cyanobacterial Toxins*. Royal Society of Chemistry, Cambridge, UK. p. 172.

Chan, T. C. , Siwak, E. B. , and Hewetson, J. F. (1991) Anti-idio-based vaccines against biological weapons. *Toxicol Appl Pharmacol* 108: 183–193.

Chellappa, N. T. , Costa, M. A. A. M. , and Marinho, I. R. (2000) Harmful cyanobacterial blooms from semi-arid freshwater ecosystems of Northeast Brazil. *Aus Soc Limnol (Newsletter)* 38: 45–49.

Chen, H.-M. , Lin, C.-H. , and Wang, T. M. (1996) Effects of 4-aminopurine on STX intoxication. *Toxicol Appl Pharmacol* 141: 44–48.

Chin, D. T. , and Cheng, C. Y. (1985) Oxidation of phenol with AC electrolysis. *Electrochem Sci Technol* 132: 2605–2611.

Choi, H. , Stathatos, E. , Dinoyisiou, D. D. (2006) Photocatalytic TiO₂ films and membranes for the development of efficient wastewater treatment and reuse systems. *Desalination* 202: 199–206.

- Chorus, I. (2005) Current Approaches to Cyanotoxin Risk Assessment, Risk Management and Regulations in Different Countries. Federal Environmental Agency, Berlin, Germany.
- Chorus, I. , and Bartram, J. (1999) Toxic Cyanobacteria in Water: A Guide to Public Health Consequences, Monitoring and Management. E & FN Sport, London, UK.
- Christiansen, G. , Fastner, J. , Erhard, M. , Borner, T. , and Dittmann, E. (2003) Microcystin biosynthesis in *Planktothrix*: Genes, evolution, and manipulation. *J Bacteriol* 185: 564–572.
- Christiansen, G. , Kurmayer, R. , Liu, Q. , and Boerner, T. (2006) Transposons inactivate biosynthesis of nonribosomal peptide microcystin in naturally occurring *Planktothrix* spp. *Appl Environ Microbiol* 72: 117–123.
- Christiansen, G. , Molitor, C. , Philmus, B. , and Kurmayer, R. (2008) Nontoxic strains of cyanobacteria are the result of major gene deletion events induced by a transposable element. *Mol Biol Evol* 25: 1695–1704.
- Chu, F. S. , Huang, X. , and Wei, R. D. (1990) Enzyme-linked immunosorbent assay for microcystins in blue-green algal blooms. *J Assoc Anal Chem* 73: 451–456.
- Chu, F. S. , Huang, X. , Wei, R. D. , and Carmichael, W. W. (1989) Production and characterization of antibodies against microcystins. *Appl Environ Microbiol* 55: 1928–1933.
- Clarke, P. B. S. , and Reuben, M. (1996) Release of [3 H]-noradrenaline from rat hippocampal synaptosomes by nicotine: Mediation of different nicotinic receptor subtypes from striatal [3 H]-dopamine release. *Br J Pharmacol* 117: 595–606.
- Codd, G. A. (1995) Cyanobacterial toxins: occurrence, properties and biological significance. *Water Sci Technol* 32: 149–156.
- Codd, G. A. (2000) Cyanobacterial toxin, the perception of water quality, and the prioritisation of eutrophication control. *Ecol Eng* 16: 51–60.
- Codd, G. A. , and Poon, G. K. (1988) Cyanobacterial toxins. *Proc Phytochem Soc Eur* 28: 283–296.
- Codd, G. A. , Bell, S. G. , and Brooks, W. P. (1989) Cyanobacterial toxins in water. *Water Sci Technol* 21: 1–13.
- Codd, G. A. , Bell, S. G. , Kaya, K. , Ward, C. J. , Beattie, K. A. , and Metcalf, J. S. (1999) Cyanobacterial toxins, exposure routes and human health. *Eur J Phycol* 34: 405–415.
- Codd, G. A. , Edwards, C. , Beattie, K. A. , Lawton, W. A. , Campbell, D. L. , and Bell, S. G. (1995) Toxins from cyanobacteria (blue-green algae). In Wiessner, W. , Schnepf, E. , and Starr, R. C. (Eds.) *Algae, Environment and Human Affairs*. Bioprocess Ltd., Bristol, England, UK. pp. 1–7.
- Codd, G. A. , Morrison, L. F. and Metcalf, J. S. (2005) Cyanobacterial toxins: Risk management and health protection. *Toxicol Appl Pharmacol* 203: 264–272.
- Cohen, P. (1989) The structure and regulation of protein phosphatases. *Annu Rev Biochem* 58: 453–508.
- Cominellis, C. H. , and Plattner, E. (1995) Electrochemical wastewater treatment. *Chimia* 42: 250–252.
- Cook, C. M. , Vardaka, E. , and Lanaras, T. (2004) Toxic cyanobacteria in Greek waters, 1987–2000: Occurrence, toxicity, and impacts in the Mediterranean region. *Acta Hydrochim Hydrobiol* 32: 107–124.
- Costa, I. A. S. , Araujo, M. F. F. , and Chellappa, N. T. (2001) Contribution to our knowledge of cyanobacteria from Brazil. Toxin producing species from a eutrophicated reservoir of Rio Grande do Norte State. *Proc Plankton Symp Espinho-Portugal*. p. 1999.
- Costa, I. A. S. , Azevedo, S. M. F. O. , Senna, P. A. C. , Bernardo, R. R. , Costa, S. M. , and Chellappa, N. T. (2006) Occurrence of toxin-producing cyanobacteria blooms in a Brazilian semiarid reservoir. *Braz J Biol* 66: 211–219.
- Cousins, I. T. , Bealing, D. J. , James, H. A. , and Sutton, A. (1996) Biodegradation of microcystin-LR by indigenous mixed bacterial populations. *Water Res* 30: 481–485.
- Cox, P. A. , Banack, S. A. , and Murch, S. J. (2003) Biomagnification of cyanobacterial neurotoxins and neurodegenerative disease among Chamorro people of Guam. *Proc. Natl Acad Sci USA* 100: 13330–13383.
- Cox, P. A. , Banack, S. A. , Murch, S. J. , Rasmussen, U. , Tien, G. , Bidigare, R. R. , Metcalf, J. S. , Morrison, L. F. , Codd, G. A. , and Bergman, B. (2005) Diverse taxa of cyanobacteria produce β -N-methylamino-L-alanine, a neurotoxic amino acid. *Proc Natl Acad Sci USA* 102: 5074–5078.
- Craig, M. , Luu, H. A. , McCready, T. L. , Williams, D. , Anderson, R. J. , and Holmes, C. F. B. (1996) Molecular mechanisms underlying the interaction of motuporin and microcystins with type-1 and type-2A protein phosphatases. *Biochem Cell Biol* 74: 569–578.
- Craig, M. , McCready, L. , Luu, H. A. , Smillie, M. A. , Dubord, P. , and Holmes, C. F. B. (1993) Identification and characterization of hydrophobic microcystins in Canadian freshwater cyanobacteria. *Toxicon* 31: 1541–1549.
- Cremer, J. , and Henning, K. (1991) Application of reversed-phase medium-pressure liquid chromatography to the isolation, separation and amino acid analysis of two closely related peptide toxins of the cyanobacterium *Microcystis aeruginosa* strain PCC 7806. *J Chromatogr* 587: 71–80.
- Curtis, S. E. (1987) Genes encoding the beta and epsilon subunits of the proton-translocating ATPase from *Anabaena* sp. strain PCC 7120. *J Bacteriol* 169: 80–86.
- Cuvin-Aralar, M. L. , Fastner, J. , Focken, U. , Becker, K. , and Aralar, E. V. (2002) Microcystins in natural blooms and laboratory cultured *Microcystis aeruginosa* from Laguna de Bay, Philippines. *Syst Appl Microbiol* 25: 179–182.
- Czarnecki, O. , Henning, M. , Lippert, I. , and Welker, M. (2006) Identification of peptide metabolites of *Microcystis* (Cyanobacteria) that inhibit trypsin-like activity in planktonic herbivorous *Daphnia* (Cladocera). *Environ Microbiol* 8: 77–87.
- Dahlmann, E. , Gerdt, W. , and Hummert, H. P. (2005) Overview of key phytoplankton toxins and their recent occurrence in the North and Baltic Seas. *Environ Toxicol* 20: 1–17.
- Dahlmann, J. , and Luckas, B. (2005) Microcystin analysis in drinking and surface water using a highly sensitive LC/MS/MS direct injection technique. www.appliedbiosystems.com.
- Dasey, M. , Ryan, N. , Wilson, J. , McGregor, G. , Fabbro, L. , Neilan, B. A. , Burns, B. P. , Kankaanpää, H. , Morrison, L. F. , Codd, G. A. , Rissik, D. , and Bowling, L. (2005) Investigations into the taxonomy, toxicity and ecology of benthic cyanobacterial accumulations in Myall Lake, Australia. *Marine Freshwater Res* 56: 45–55.
- Davidson, F. F. (1959) Poisoning of wild and domestic animals by a toxic water bloom of *Nostoc rivulare* Kuetz. *J Am Water Works Assoc* 51: 1277–1287.
- Dawson, J. F. , and Holmes, C. F. B. (1999) Molecular mechanisms underlying inhibition of protein phosphatases by marine toxins. *Frontiers in Bioscience* 4: 646–658.
- Dawson, R. M. (1998) The toxicology of microcystins. *Toxicon* 36: 953–962.
- De Bernardi, R. , and Giussani, G. (1988) Discrimination between algae and artificial particles by freshwater and marine copepods. *Limnol Oceanogr* 33: 397–408.

- De Bernardi, R. , and Giussani, G. (1990) Are blue-green algae a suitable food for zooplankton? An overview. *Hydrobiologia* 200/201: 29–41.
- De Figueiredo, D. R. , Azeiteiro, U. M. , Esteves, S. M. , Goncalves, F. J. M. , and Pereira, M. J. (2004) Microcystin-producing blooms-a serious global public health issue. *Ecotoxicol Environ Saf* 59: 151–163.
- DeMott, W. R. , and Dhawale, S. (1995) Inhibition of in vitro protein phosphatase activity in three zooplankton species by microcystin-LR, a toxin from cyanobacteria. *Arch Hydrobiol* 134: 417–424.
- DeMott, W. R. , Zhang, O.-X. , and Carmichael, W. (1991) Effects of toxic cyanobacteria and purified toxins on the survival and feeding of a copepod and three species of *Daphnia*. *Limnol Oceanogr* 36: 1346–1357.
- de Silva, E. D. , Williams, D. E. , Anderson, R. J. , Klix, H. , Holmes, C. F. B. , and Allen, T. M. (1992) Motuporin, a potent protein phosphatases inhibitor isolated from the Papua New Guinea sponge *Theonella swinhoei* Gray. *Tetrahedron Lett* 33: 1561–1564.
- Devlin, J. P. , Edwards, O. E. , Gorham, P. R. , Hunter, N. R. , Pike, R. K. , and Stavric, B. (1977) Anatoxin-a, a toxic alkaloid Z from *Anabaena flos-aquae* NRC-44-1. *Can J Chem* 55: 1367–1371.
- Diehnelt, C. W. , Dugan, N. R. , Peterman, S. M. , and Budde, W. L. (2006) Identification of microcystin toxins from a strain of *Microcystis aeruginosa* by liquid chromatography introduction into a hybrid linear ion trap-Fourier transform ion cyclotron resonance mass spectrometer. *Anal Chem* 78: 501–512.
- Dillenberg, H. O. , and Dehnelt, M. K. (1960) Toxic water bloom in Saskatchewan, 1959. *Can Med Assoc J* 83: 1151–1154.
- Ding, W. X. , Shen, H.M. , Zhu, H. G. , Lee, B. L. , and Ong, C. N. (1999) Genotoxicity of *Microcystis cyanobacteria* extract of a water source in China. *Mutat Res* 442: 69–74.
- Dittmann, E. , Meissner, K. , and Boerner, T. (1996) Conserved sequences of peptide synthetase genes in the cyanobacterium *Microcystis aeruginosa*. *Phycologia* 35 (Suppl 6): 62–67.
- Dittmann, E. , Neilan, B. A. , Erhard, M. , von Doehren, H. , and Boerner, T. (1997) Insertional mutagenesis of a peptide synthetase gene that is responsible for hepatotoxin production in the cyanobacterium *Microcystis aeruginosa* PCC 7806. *Mol Microbiol* 26: 779–787.
- Domanski, T. L. , de Jonge, B. L. M. , and Bayles, K. W. (1997) Transcriptional analysis of the *Staphylococcus aureus* gene encoding penicillin-binding protein 4. *J Bacteriol* 179: 2651–2657.
- Domingos, P. , Rubin, T. K. , Molica, R. J. R. , Azevedo, S. M. F. O. , and Carmichael, W. W. (1998) First report of microcystin production by picoplanktonic cyanobacteria isolated from northeast Brazilian drinking water supply. *Environ Toxicol* 14: 31–35.
- Douglas, P. , Moorhead, G. B. G. , Ye, R. , and Lees-Millers, S. P. (2001) Protein phosphatases regulate DNA-dependent protein kinase activity. *J Biol Chem* 276: 18992–18998.
- Dow, C. S. , and Swoboda, U. K. (2000) Cyanotoxins. In: Whitton, B. A. , and Potts, M. (Eds) *The Ecology of Cyanobacteria*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 614–632.
- Downing, J. A. , Watson, S. B. , and Mc Cauley, E. (2001) Predicting cyanobacteria dominance in lakes. *Can J Fish Aquat Sci* 58: 1905–1908.
- Draisci, R. , Ferretti, E. , Palleschi, L. , and Marchiafava, C. (2001) Identification of anatoxins in blue-green algae food supplements using liquid chromatography-tandem mass spectrometry. *Food Additives and Contaminants* 18: 525–531.
- Drikas, M. (1994) Control and/or removal of toxins. In: Steffensen, D. A. , and Nicholson, B. C. (Eds.) *Toxic Cyanobacteria: Current Status of Research and Management*. Australian center for water quality, Salisbury, Australia. p. 93
- Drikas, M. , and Hrudef, S. (1994) Control and removal of toxins: Summary of discussions. In: Steffensen, D. , and Nicholson, B. C. (Eds.) *Toxic Cyanobacteria. Current status of Research and Management*. American Water Works Association Research Foundation, Denver, CO, USA.
- Duy, T. N. , Lam, P. K. S. , Shaw, G. R. , and Connell, D. W. (2000) Toxicology and risk assessment of freshwater cyanobacterial (Blue-green algal) toxins in water. *Rev Environ Contam Toxicol* 163: 113–186.
- Dvorakova, D. , Dvorakova, K. , Blaha, L. , Marsalek, B. , and Knotkova, Z. (2002) Effects of cyanobacterial biomass and purified microcystins on malformations in *Xenopus laevis*: Teratogenesis assay (FETAX). *Environ Toxicol* 17: 547–555.
- Eaglesham, G. K. , Norris, R. L. , Shaw, G. R. , Smith, M. J. , Chiswell, R. K. , Davis, R. K. , Neville, G. R. , Seawright, A. A. , and Moore, M. R. (1999) Use of HPLC-MS/MS to monitor cylindrospermopsin, a blue-green algal toxin, for public health purposes. *Environ Toxicol* 14: 151–154.
- Edler, L. , Ferno, S. , Lind, M. G. , Lundberg, R. , and Nilsson, P. O. (1985) Mortality of dogs associated with bloom of the cyanobacterium *Nodularia spumigena* in the Baltic Sea. *Ophelia* 24: 103–109.
- Edwards, C. , Beattie, K. A. , Scrimgeour, C. H. , and Codd, G. A. (1992) Identification of anatoxin-a in benthic cyanobacteria (blue-green algae) and in associated dog poisonings at Loch Insh, Scotland. *Toxicon* 30: 1165–1175.
- Ehrenreich, I. M. , Waterbury, J. B. , and Webb, E. A. (2005) Distribution and diversity of natural product genes in marine and freshwater cyanobacterial cultures and genomes. *Appl Environ Microbiol* 71: 7401–7413.
- Ells, B. , Froese, K. , Hrudef, S. E. , Purves, R. W. , Guevremont, R. , and Barnett, D. A. (2000) Detection of microcystins using electrospray ionization high-field asymmetric waveform ion mobility mass spectrometry/mass spectrometry. *Rapid Commun Mass Spectrom* 14: 1538–1542.
- Elleman, T. C. , Falconer, I. R. , Kackson, A. R. B. , and Runnegar, M. T. (1978) Isolation, characterization and pathology of the toxin from a *Microcystis aeruginosa* (= *Anacystis cyanea*) bloom. *Aus J Biol Sci* 31: 209–218.
- Erhard, M. , von Doehren, H. , and Jungblut, P. (1997) Rapid typing and elucidation of new secondary metabolites of intact cyanobacteria using MALDI-TOF mass spectrometry. *Nat Biotechnol* 15: 906–909.
- Eriksson, J. E. , Hagerstrand, H. , and Isomaa, B. (1987) Cell selective cytotoxicity of peptide toxin from the cyanobacterium *Microcystis aeruginosa*. *Biochim Biophys Acta* 930: 304–310.
- Eriksson, J. E. , Meriluoto, J. A. , Kujari, H. P. , Osterlund, K. , Fagerlund, K. , and Hallbom, L. (1988) Preliminary characterization of a toxin isolated from the cyanobacterium *Nodularia spumigena*. *Toxicon* 26: 161–166.
- Eriksson, J. E. , Groenberg, L. , Nygard, S. , Slotte, J. R. , and Meriluto, J. A. O. (1990a) Hepatocellular uptake of 3 H-dihydroxymicrocystin LR, a cyclic peptide toxin. *Biochim Biophys Acta* 1025: 60–66.
- Eriksson, J. E. , Paatero, G. I. L. , Meriluoto, J. A. O. , Codd, G. A. , Kass, G. E. N. , Nicotera, P. , and Orrenius, S. (1989) Rapid micro filament reorganization induced in isolated rat hepatocytes by microcystin-LR, a cyclic peptide toxin. *Exp Cell Res* 185: 86–100.
- Erikson, J. E. , Toivola, D. , Meriluto, J. A. O. , Karaki, H. , Han, Y.-G. , and Hartshorne, D. (1990b) Hepatocyte deformation induced by cyanobacterial toxins reflects inhibition of protein phosphatases. *Biochem Biophys Res Commun* 173: 1347–1353.

Ernst, B. , Hoeger, S. J. , O'Brien, E. , and Dietrich, D. R. (2006) Oral toxicity of microcystin-containing cyanobacterium *Planktothrix rubescens* in European whitefish (*Coregonus lavaretus*). *Aquat Toxicol* 79: 31–40.

Evans, T. M. , Schillinger, J. E. , and Stuart, D. G. (1978) Rapid determination of bacteriological water quality by using *Limulus* lysate. *Appl Environ Microbiol* 35: 376–382.

Eynard, F. , Mez, K. , Walther, J.-L. (2000) Risk of cyanobacterial toxins in Riga waters. *Water Res* 34: 2979–2988.

Falconer, I. R. (1991) Tumor promotion and liver injury caused by oral consumption of cyanobacteria. *Environ Toxicol Water Qual* 6: 177–184.

Falconer, I. R. (1993) Mechanism of toxicity of cyclic peptide toxins from blue-green algae. In: Falconer, I. R. (Ed.) *Algal Toxins in Seafood and Drinking Water*. Academic Press, London, UK. pp. 1538–1542.

Falconer, I. R. (1998) Algal toxins and human health. In: Hrubec, J. (Ed.) *The Handbook of Environmental Chemistry*, Vol. 5 part C, Springer-Verlag, Berlin, Germany. pp. 53–82.

Falconer, I. R. (2005) Cyanobacterial poisoning of livestock and people. In: Falconer, I. R. (Ed.) *Cyanobacterial Toxins of Drinking Water Supplies. Cyndrospermopsins and Microcystins*. CRC Press, Boca Raton, Florida, FL, USA.

Falconer, I. R. , and Humpage, A. R. (1996) Tumor promotion by cyanobacterial toxins. *Phycologia* 35 (Suppl. 6): 74–79.

Falconer, I. R. , and Yeung, D. S. (1992) Cytoskeletal changes in hepatocytes induced by *Microcystis* toxins and their relation to hyperphosphorylation of cell proteins. *Chem Biol Interact* 81: 181–196.

Falconer, I. R. , Beresford, A. M. , and Runnegar, M. T. C. (1983) Evidence of liver damage by toxin from a bloom of the blue-green alga, *Microcystis aeruginosa*. *Med J Aus* 1: 511–514.

Falconer, I. R. , Buckley, T. , and Runnegar, M. T. (1986) Biological half-life, organ distribution and excretion of ¹²⁵I-labelled toxic peptide from the blue-green alga *Microcystis aeruginosa*. *Aus J Biol Sci* 39: 17–21.

Falconer, I. R. , Burch, M.D. , Steffensen, D. A. , Choice, M. , and Coverdale, O. R. (1994) Toxicity of blue-green alga (cyanobacterium) *Microcystis aeruginosa* in drinking water to growing pigs, as an animal model for human injury and risk assessment. *J Environ Toxicol Water Qual* 9: 131–139.

Falconer, I. R. , Choice, A. , and Hosja, W. (1992) Toxicity of edible mussels (*Mytilus edulis*) growing naturally in an estuary during a water bloom of the blue-green alga *Nodularia spumigena*. *J Environ Toxicol Water Qual* 9: 131–139.

Falconer, I. R. , Hardy, S. J. , Humpage, A. R. , Froschio, S. M. , Tozer, G. J. , and Hawkins, P. R. (1999) Hepatic and renal toxicity of the blue-green alga (cyanobacterium) *Cylindrospermopsis raciborskii* in male Swiss albino mice. *Environ Toxicol* 14: 143–150.

Falconer, I. R. , Runnegar, M. T. C. , and Huynh, V. L. (1983) Effectiveness of activated carbon in the removal of algal toxin from potable water supplies: A pilot investigation. In: Tenth Federal Convention of Australian Water and Wastewater Association, Sydney, Australia. pp. 1–8.

Fastner, J. , Erhard, M. , and von Doehren, H. (2001) Determination of oligopeptide diversity within a natural population of *Microcystis* spp. (Cyanobacteria) by typing single colonies of matrix-assisted laser desorption ionization-time of flight mass spectrometry. *Appl Environ Microbiol* 67: 5069–5076.

Fawell, J. K. , James, C. P. , and James, H. A. (1994) Toxins from blue-green algae: Toxicological assessment of microcystin-LR and a method for its determination in water. Water Research Centre, Medmenham, UK. pp 1–16.

Feitz, A. J. , and Waite, T. D. (2003) Kinetic modeling of TiO₂ -catalyzed photodegradation of trace levels of microcystin-LR. *Environ Sci Technol* 37: 561–568.

Feng, C. , Sugiura, N. , Shimada, S. , and Maekawa, T. (2003) Development of a high performance electrochemical wastewater treatment system. *J Hazard Matter* 103: 65–78.

Feng, C. , Sugiura, N. , Masaoka, Y. , and Maekawa, T. (2005) Electrochemical degradation of microcystin-LR. *J Environ Sci Health A* 40: 453–465.

Fergusson, K. M. , and Saint, C. P. (2000) Molecular phylogeny of *Anabaena circinalis* and its identification in environmental samples by PCR. *Appl Environ Microbiol* 66: 4145–4148.

Ferreria, F. M. B. , Soler, J. M. , Fidalgo, M. L. , and Vila, P. F. (2001) PSTs from *Aphanizomenon flos-aquae* (cyanobacteria) collected in the Crestuma-Lever reservoir (Duro River, northern Portugal). *Toxicon* 39: 757–761.

Fewer, D. P. , Tooming-Klunderud, A. , Jokela, J. , Wahlsten, M. , Rouhiainen, L. , Kristensen, T. , Rohrlack, T. , Jakobsen, K. S. , and Sivonen, K. (2008) Natural occurrence of microcystin synthetase deletion mutants capable of producing microcystins in the genus *Anabaena* (cyanobacteria). *Microbiology* 154: 1007–1014.

Fischer, W. J. , and Dietrich, D. R. (2000) Pathological and biochemical characterization of microcystin-induced hepatopancreas and kidney damage in carp (*Cyprinus carpio*). *Toxicol Appl Pharmacol* 164: 73–81.

Fischer, W. J. , Hitzfeld, B. C. , Tencalla, F. , Eriksson, J. E. , Mikhailov, A. , and Dietrich, D. R. (2000) Microcystin LR toxicodynamics, induced pathology, and immunohistochemical localization in livers of blue-green algae exposed rainbow trout (*Oncorhynchus mykiss*). *Toxicol Sci* 54: 365–373.

Fitzepore, R. B. , Clark, S. A. , and Keevil, C. W. (1994) Routes of intoxication. In: Codd, G. A. , Jeffries, T. M. , Keevil, C. W. , and Potter, E. (Eds.) *1st International Symposium on Detection methods for cyanobacterial (blue-green algal) toxins*. Royal Society of Chemistry, Cambridge, UK. pp. 69–74.

Fitzgerald, D. J. (2001) Cyanotoxins and human health-overview. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes and Consequences*. Springer, Berlin, Germany. pp. 179–190.

Fitzgerald, D. J. , and Yamasaki, H. (1990) Tumor promotion: Models and assay systems. *Teratogen, Carcinogen, Mutagen* 10: 89–102.

Fladmark, K. E. , Brustugun, O. T. , Hovald, R. , Boe, R. , Gjertsen, B. T. , Zhivotovsky, B. , and Doskeland, S. O. (1999) Ultrarapid scapase-3 dependent apoptosis induction by serine/threonine phosphatase inhibitors. *Cell Death and Differentiation* 6: 1099–1108.

Fladmark, K. E. , Serres, M. H. , Lersen, N. L. , Yasumoto, T. , Aune, T. , and Doskeland, S. O. (1998) Sensitive detection of apoptogenic toxins in suspension cultures of rat and salmon hepatocytes. *Toxicon* 36: 1101–1114.

Fleming, L. E. , Rivero, C. , Burns, J. , Williams, C. , Bean, J. A. , Shea, K. A. , and Stinn, J. (2002) Blue-green algal (cyanobacterial) toxins, surface drinking water, and liver cancer in Florida. *Harmful Algae* 1: 157–168.

Flett, D. J. , and Nicholson, B. C. (1991) Toxic Cyanobacteria in Water Supplies: Analytical Techniques. Urban Water Research Association of Australia. 61 pp.

Foulds, I. V. , Granacki, A. , Xiao, C. , Krull, U. J. , Castle, A. , and Horgen, P. A. (2002) Quantification of microcystin-producing cyanobacteria by 5'-nuclease PCR. *J Appl Microbiol* 93: 825–834.

Fox, A. M. , and Dulay, T. M. (1993) Heterogeneous photocatalysis. *Chem Rev* 93: 341–357.

Francis, G. (1878) Poisonous Australian lake. *Nature* (London) 18: 11–12.

Frangoul, L. , Quillardet, P. , Castets, A. M. , Humbert, J-F. , Matthijs, H. C. P. , Cortez, D. , Tolonen, A. , Zhang, G-C. , Gribaldo, S. , Kehr, J-C. , Zilliges, Y. , Ziemert, N. , Becker, S. , Talla, E. , Latifi, A. , Billault, A. , Lepelletier, A. , Dittmann, E. , Bouchier, C. , and Tandeau de Marsac, N. (2008) Highly plastic genome of *Microcystis aeruginosa* PCC 7806, a ubiquitous toxic freshwater cyanobacterium. *BMC Genomics* 9: 274 doi:10.1186/1471-2164-9-274.

Frank, C. A. (2002) Microcystin-producing cyanobacteria in recreational waters in southwestern Germany. *Environ Toxicol* 17: 361–366.

Fromme, H. , Koehler, A. , Krause, R. , and Fuehring, D. (2000) Occurrence of cyanobacterial toxins-microcystins and anatoxin-a—in Berlin water bodies with implications to human health and regulations. *Environ Toxicol* 15: 120–130.

Fujishima, A. , Hashimoto, K. , and Watanabe, T. (1999) TiO₂ Photocatalysis-Fundamentals and Applications. BKC, Tokyo, Japan.

Fujuki, H. , and Suganuma, M. (1993) Tumor promotion by inhibitors of protein phosphatase 1 and 2A: The okadaic acid class of compounds. *Adv Cancer Res* 61: 143–196.

Fujuki, H. , Suganuma, M. , Suguri, H. , Yoshizawa, S. , Takagi, K. , Nakayasu, M. , Ojika, M. , Yamada, K. , Yasumoto, T. , Moore, R. E. , and Sugimura, T. (1990) New tumor promoters from marine natural products. In: Hall, S. , and Strichartz, (Eds.) *Marine Toxins: Origin, Structure and Molecular Pharmacology*. American Chemical Society, Washington, D. C. USA. pp. 232–240.

Fulton, R. S. III , and Pearl, H. W. (1987) Toxic and inhibitory effects of the blue-green alga *Microcystis aeruginosa* on herbivorous zooplankton. *J Plankton Res* 9: 837–855.

Furey, A. , Crowley, J. , Lehane, M. , and James, K. J. (2003a) Liquid chromatography with electron spray ion-trap mass spectrometry for the determination of anatoxins in cyanobacteria and drinking water. *Rapid Commun Mass Spectrometry* 17: 583–588.

Furey, A. , Crowley, J. , Shuilleabhain, A. N. , Skulberg, O. M. , and James, K. J. (2003b) The first identification of the rare cyanobacterial toxin, homoanatoxin-a, in Ireland. *Toxicon* 41: 297–303.

Galat, D. L. , Verdin, J. P. , and Sims, L. L. (1990) Large-scale patterns of *Nodularia spumigena* blooms in Pyramid Lake, Nevada, determined from Landsat imagery: 1972–1986. *Hydrobiologia* 197: 147–164.

Galey, F. D. , Beasley, V. R. , Carmichael, W. W. , Kleppe, G. , Hooser, S. B. , and Haschek, W. M. (1987) Blue-green algae (*Microcystis aeruginosa*) hepatotoxicosis in dairy cows. *Am J Vet Res* 48: 1415–1420.

Gallon, J. R. , Chit, K. N. , and Brown, E. G. (1990) Biosynthesis of the tropane-related cyanobacterial toxin anatoxin-a: Role of ornithine decarboxylase. *Phytochemistry* 29: 1107–1111.

Gallon, J. R. , Kittakoop, O. , and Brown, E. G. (1994) Biosynthesis of anatoxin-a by *Anabaena flos-aquae*: Examination of primary enzymatic steps. *Phytochemistry* 35: 1195–1203.

Gathercole, P. S. , and Thiel, P. G. (1987) Liquid chromatographic determination of the cyanoginosins, toxins produced by the cyanobacterium *Microcystis aeruginosa*. *J Chromatogr* 408: 435–440.

Gauss, C.-M. , Sheppock, J. E. , Narin, A. C. , and Chamberlin, R. A. (1997) A molecular modeling analysis of the binding interactions between okadaic acid class of natural product inhibitors and the ser-thr phosphatases, PP1 and PP2A. *Bioorganic Medicinal Chem* 5: 1751–1773.

Gehringer, M. M. , Downs, K. S. , Downing, T. G. , Naude, R. J. , and Shephard, E. G. (2003a) An investigation into effect of selenium supplementation on microcystin hepatotoxicity. *Toxicon* 41: 451–458.

Gehringer, M. M. , Govender, S. , Shah, M. , and Downing, T. G. (2003b) An investigation of the role of vitamin E in the protection of mice against microcystin toxicity. *Environ Toxicol* 18: 142–148.

Gerwick, W. H. , Tan, L. T. , and Sitachitta, N. (2001) Nitrogen-containing metabolites from marine cyanobacteria. *Alkaloids Chem Biol* 57: 75–184.

Gessner, B. D. , Bell, P. , Doucette, G. J. , Moczydlowski, E. , Pli, M. A. , Van Dolah, F. , and Hall, S. (1997) Hypertension and identification of toxin in human urine and serum following a cluster of mussel-associated paralytic shellfish poisoning outbreaks. *Toxicon* 35: 711–722.

Ghassempour, A. , Najafi, N. M. , Mehdina, A. , Davarani, S. S. , Fallahi, M. , and Nakhshab, M. (2005) Analysis of anatoxin-a using polyaniline as a sorbent in solid-phase microextraction coupled to gas chromatography-mass spectrometry. *J Chromatogr* 1078: 120–127.

Giani, A. , Bird, D. F. , Prairie, Y. T. , and Lawrence, J. F. (2005) Empirical study of cyanobacterial toxicity along a trophic gradient of lakes. *Can J Fish Aquat Sci* 62: 2100–2109.

Gibson, C. E. , and Smith, R. V. (1982) Freshwater plankton. In: Carr, N. G. , and Whitton, B. A. (Eds.) *The Biology of Cyanobacteria*. Blackwell Scientific Publications, Oxford, UK. pp. 463–489.

Gkelis, S. , Moustaka-Gouni, M. , Sivonen, K. , and Lanaras, T. (2005) First report of the cyanobacterium *Aphanizomenon ovalisporum* Forti in two Greek lakes and cyanotoxin occurrence. *J Plankton Res* 27: 1295–1300.

Goldberg, J. , Huang, H. B. , Kwon, Y. G. , Greengard, P. , Narin, A. C. , and Kuriyan, J. (1995) Three-dimensional structure of the catalytic subunit of protein serine/threonine phosphatase-1. *Nature* (London) 376: 745–753.

Gorham, P. R. (1964) Toxic algae. In: Jackson, D. F. (Ed.) *Algae and Man*, Plenum Press, New York, NY, USA. pp. 307–336.

Gorham, P. R. , and Carmichael, W. W. (1988) Hazards of freshwater blue-green algae (cyanobacteria). In: Lembi, C. A. , and Waaland, J. R. (Eds.) *Algae and Human Affairs*. Cambridge University Press, Cambridge, UK. pp. 403–431.

Grabow, W. O. , Du Randt, W. C. , and Scott, W. E. (1982) *Microcystis aeruginosa* toxin: Cell culture toxicity, hemolysis and mutagenicity assays. *Appl Environ Microbiol* 43: 1425–1433.

Graham, J. L. , Jones, J. R. , Jones, S. B. , Downing, J. A. , Clevenger, T. E. (2004) Environmental factors influencing microcystin distribution and concentration in the Midwestern United States. *Water Res* 38: 4395–4404.

Griffiths, D. J. , and Saker, M. L. (2003) The Palm Island Mystery Disease 20 years on: A review of research on the cyanotoxin cylindrospermopsis. *Environ Toxicol* 18: 79–93.

Gugger, M. , Lenoir, S. , Berger, C. , Ledreux, A. , Druart, J. C. , Humbert, J. F. , Guette, C. , and Bernard, C. (2005) First report in a river in France of the benthic cyanobacterium *Phormidium favosum* producing anatoxin-a associated with dog neurotoxicosis. *Toxicon* 45: 919–928.

Gugger, M. , Molica, R. , Berre, B. L. , Dufour, P. , Bernard, C. , and Humbert, J.-F. (2005) Genetic diversity of *Cylindrospermopsis* strains (cyanobacteria) isolated from four continents. *Appl Environ Microbiol* 71: 1097–1100.

Gupta, N. , Bhaskar, A. S. B. , and Rao, P. V. L. (2002) Growth characteristics and toxin production in batch cultures of *Anabaena flos-aquae*: Effects of culture media and duration. *World J Microbiol Biotechnol* 18: 29–35.

Gupta, S. , Giddings, M. , and Sheffer, M. (2001) Cyanobacterial toxins in drinking water: A Canadian perspective. In Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes and Consequences*. Springer, Berlin, Germany. pp. 208–212.

Gussmann, H. , Molzhan, M. J. , and Bicks, B. (1985) Vergiftungen bei jungtieren durch die Blaualge *Nodularia spumigena*. *Montash Veterinaermed* 40: 76–79. (In German) Cited from

Sivonen, K. , Kononen, K. , Carmichael, W. W. , Dahlem, A. M. , Rinehart, K. L. , Kiviranta, J. , Niemela, S. I. (1989) Occurrence of the hepatotoxic cyanobacterium *Nodularia spumigena* in the Baltic Sea and structure of the toxin. *Appl Environ Microbiol* 55: 1990–1995.

Guzman, R. E. , and Solter, P. F. (2002) Characterization of sublethal microcystin-LR exposure in mice. *Vet Pathol* 39: 17–26.

Hagmann, L. , and Juettner, F. (1996) Fischerellin-A, a novel photosystem-II inhibiting allelochemical of the cyanobacterium *Fischerella muscicola* with antifungal and herbicidal activity. *Tetrahedron Lett* 37: 6539–6542.

Haider, S. , Naithani, V. , Viswanathan, P. N. , and Kakkar, P. (2003) Cyanobacterial toxins: A growing environmental concern. *Chemosphere* 52: 1–21.

Halinen, K. , Jokela, J. , Fewer, D. P. , Wahlsten, M. , and Sivonen, K. (2007) Direct evidence that production of microcystins by *Anabaena* strains from the Baltic Sea. *Appl Environ Microbiol* 73: 6543–6550.

Hamilton, P. B. , Ley, L. M. , Dean, S. , and Pick, F. R. (2004) The occurrence of the cyanobacterium *Cylindrospermopsis raciborskii* in Constance Lake: An exotic cyanoprokaryote new to Canada. *Phycologia* 44: 17–25.

Haney, J. F. , Sasner, J. J. , and Ikawa, M. (1995). Effects of products released by *Aphanizomenon flos-aquae* and purified STX on the movements of *Daphnia carinata* feeding appendages. *Limnol Oceanogr* 40: 263–272.

Harada, K.-I. , (1995) Chemistry and detection of microcystins. In: *Toxic Microcystis*. CRC Press, Boca Raton, New York, London, Tokyo. pp. 203–232.

Harada, K.-I. , Matsuura, K. , Suzuki, M. , Oka, H. , Watanabe, M. F. , Oishi, S. , Dahlem, A. M. , and Beasley, V. R. (1988a) Analysis and purification of toxic peptides from cyanobacteria by reversed-phase high-performance liquid chromatography. *J Chromatogr* 448: 275–283.

Harada, K.-I. , Matsuura, K. , Suzuki, M. , Watanabe, M. F. , Oishi, S. , Dahlem, A. M. , Beasley, V. R. , and Carmichael, W. W. (1990a) Isolation and characterization of the minor components associated with microcystins LR and RR in the cyanobacterium (blue-green algae). *Toxicon* 28: 55–64.

Harada, K.-I. , Suzuki, M. , Dahlem, A. M. , Beasley, V. R. , Carmichael, W. W. , and Rinehart, K. L. (1988b) Improved method for purification of toxic peptides produced by cyanobacteria. *Toxicon* 26: 433–439.

Harada, K.-I. , Nagai, H. , Kimura, Y. , and Suzuki, M. (1993) Liquid chromatography/mass spectrometric detection of anatoxin-a, a neurotoxin from cyanobacteria. *Tetrahedron* 49: 9251–9260.

Harada, K.-I. , Ogawa, K. , Kimura, Y. , Murata, H. , Suzuki, M. , Thorn, P. M. , Evans, W. R. , and Carmichael, W. W. (1991a) Microcystins from *Anabaena flos-aquae* NRC 525-17. *Chem Res Toxicol* 4: 535–540.

Harada, K. I. , Ogawa, K. , Matsuura, K. , Murata, H. , Suzuki, M. , Watanabe, M. F. , Itezono, Y. , and Nakayama, N. (1990b) Structural determination of geometrical isomers of microcystins-LR and -RR from cyanobacteria by two-dimensional NMR spectroscopic techniques. *Chem Res Toxicol* 3: 473–481.

Harada, K.-I. , Ogawa, K. , Matsuura, K. , Nagai, H. , Murata, H. , Suzuki, M. , Itezono, Y. , Nakayama, N. , Shirai, M. , and Nakano, M. (1991b) Isolation of two toxic heptapeptide microcystins from an axenic strain of *Microcystis aeruginosa*, K-139. *Toxicon* 29: 479–489.

Harada, K.-I. , Ohtani, I. , Iwamoto, K. , Suzuki, M. , Watanabe, M. F. , Watanabe, M. , and Terao, K. (1994) Isolation of cylindrospermopsin from a cyanobacterium *Umezakia natans* and its screening method. *Toxicon* 32: 73–84.

Harada, K.-I. , Murata, H. , Qiang, Z. , Suzuki, M. , and Kondo, F. (1996a) Mass spectrometric screening method for microcystins in cyanobacteria. *Toxicon* 34: 701–710.

Harada, K.-I. , Tsuji, K. , Watanabe, M. F. , and Kondo, F. (1996b) Stability of microcystins from cyanobacteria-III. Effect of pH and temperature. *Phycologia* 35: 83–88.

Harada, S. , Kimura, Y. , Ogawa, K. , Suzuki, M. , Dahlem, A. H. , Beasley, V. R. , and Carmichael, W. W. (1989) A new procedure for the analysis and purification of naturally occurring anatoxin-a from the blue-green alga *Anabaena flos-aquae*. *Toxicon* 27: 1289–1296.

Harrington, G. G. , Luesch, H. , Yoshida, W. Y. , Moore, R. E. , Nagle, D. G. , Park, P. U. , Biggs, J. , Paul, V. J. , Mooberry, S. L. , Corbett, T. H. , and Valeriote, F. A. (1998) Isolation, structure determination and biological activity of dolastatin 12 and linybyastatin 1 from *Lyngbya majuscula*/Schizothrix calcicola cyanobacterial assemblages. *J Nat Prod* 61: 1221–1225.

Hariston, N. G. , Holtmeier, C. L. , Lampert, W. , Weider, L. J. , Post, D. M. , and Fischer, J. M. (2001) Natural selection for grazer resistance to toxic cyanobacteria: Evolution of phenotypic plasticity. *Evolution* 55: 2203–2214.

Hart, J. , and Stott, P. (1993) Microcystin-LR removal from water. Foundation for Water Research Report, FR0367, Swindon, UK.

Hastie, C. J. , Borthwick, E. B. , Morrison, L. F. , Codd, G. A. , and Cohen, P. T. (2005) Inhibition of several protein phosphatases by non-covalently interacting microcystin and a novel cyanobacterial peptide, nostocyclin. *Biochim Biophys Acta* 1726: 187–193.

Hawkins, P. R. , Chandrasena, N. R. , Jones, G. J. , Humpage, A. R. , and Falconer, I. (1997) Isolation of *Cylindrospermopsis raciborskii* from an ornamental lake. *Toxicon* 35: 341–346.

Hawkins, P. R. , Runnegar, M. T. C. , Jackson, A. R. B. , and Falconer, I. R. (1985) Severe hepatotoxicity caused by the tropical cyanobacterium (Blue-green alga) *Cylindrospermopsis raciborskii* (Woloszynska) Seenaya and Subba Raju isolated from a domestic water supply reservoir. *Appl Environ Microbiol* 50: 1292–1295.

Hayman, J. (1992) Beyond the Barcoo-probable human tropical cyanobacterium poisoning in outback Australia. *Med J Aus* 157: 794–796.

Heinze, R. (1999) Toxicity of the cyanobacterial toxin microcystin-LR to rats after 28 days intake with drinking water. *Environ Toxicol* 14: 57–60.

Hemscheidt, T. , Rapala, J. , Sivonen, K. , and Skulberg, O. M. (1995) Biosynthesis of anatoxin-a in *Anabaena flos-aquae* and homoanatoxin-a in *Oscillatoria formosa*. *J Chem Soc Chemical Commun* 1361–1362.

Henriksen, P. (1996) Microcystin profiles and contents in Danish populations of cyanobacteria/blue-green algae as determined by HPLC. *Phycologia* (Supplement) 35: 102–110.

Henriksen, P. (2001) Toxic freshwater cyanobacteria in Denmark. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes and Consequences*. Springer Verlag, KG, Berlin, Germany, pp. 49–56.

Henriksen, P. , Carmichael, W. W. , An, J. , and Moestrup, Ø. (1997) Detection of an anatoxin-a(s)-like anticholinesterase in natural blooms and cultures of cyanobacteria/blue-green algae from Danish lakes and in the stomach contents of poisoned birds. *Toxicon* 35: 901–913.

Heresztyn, T. , and Nicholson, B. C. (1997) Nodularin concentrations in Lakes Alexandria and Albert, South Australia, during a bloom of the cyanobacterium (blue-green alga) *Nodularia spumigena* and degradation of the toxin. *Environ Toxicol Water Quality* 12: 273–282.

Hesse, K. , and Kohl, J.-G. (2001) Effects of light and nutrient supply on growth and microcystin content of different strains of *Microcystis aeruginosa*. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes and Consequences*. Springer Verlag, KG, Berlin, Germany, pp. 152–158.

Hilborn, E. D. , Carmichael, W. W. , Wayne, W. , Yuan, M. , Azevedo, S. M. F. O. (2005) A simple colorimetric method to detect biological evidence of human exposure to microcystins. *Toxicon* 46: 218–221.

Hindak, F. (1988) Planktonic species of two related genera, *Cylindrospermopsis* and *Anabaenopsis*, from western Slovakia. *Arch Hydrobiol* 80: 283–302.

Hiripi, L. , Nagy, L. , Kalmar, T. , Kovacs, A. , and Voros, L. (1998) Insect (*Locusta migratoria migratorioides*) test monitoring the toxicity of cyanobacteria. *Neurotoxicol* 19: 605–608.

Hirooka, E. Y. , Pinotti, M. H. , Tsutsumi, T. , Yoshida, F. , and Ueno, Y. (1999) Survey of microcystins in water between 1995 and 1996 in Parana, Brazil using ELISA. *Nat Toxins* 7: 103–109.

Hitzfeld, B. C. , Hoeger, S. J. , and Dietrich, D. R. (2000) Cyanobacterial toxins: Removal during drinking water treatment, and human risk assessment. *Environ Health Perspect* 108 (Suppl): 113–113.

Hoeger, S. J. , Dietrich, D. R. , and Hitzfeld, B. C. , (2002) Effect of ozonation on the removal of cyanobacterial toxins during drinking water treatment. *Environ Health Perspect* 110: 1127–1132.

Hoffmann, D. , Hevel, J. M. , Moore, R. E. , and Moore, B. S. (2003) Sequence analysis and biochemical characterization of the nostopeptolide A biosynthetic gene cluster from *Nostoc* sp. GSV 224. *Gene* 311: 171–180.

Holmes, C. F. B. , and Boland, M. P. (1993) Inhibitors of protein phosphatase-1 and -2A; two of the major serine/threonine protein phosphatases involved in cellular regulation. *Current Opin Struct Biol* 3: 934–943.

Honakanen, R. E. , Codispoti, B. A. , Tse, K. , and Boynton, A. L. (1994) Characterization of natural toxins with inhibitory activity against serine/threonine protein phosphatases. *Toxicon* 32: 339–350.

Honakanen, R. E. , Zwiller, J. , Moore, R. E. , Daily, S. L. , Khatra, B. S. , Dukelow, M. , and Boynton, A. L. (1990) Characterization of microcystin-LR, a potent inhibitor of type 1 and type 2A protein phosphatase. *J Biol Chem* 265: 19401–19404.

Hooser, S. B. , Beasley, V. R. , Lovell, R. A. , Carmichael, W. W. , and Haschek, W. M. (1991) Actin filament alterations in rat hepatocytes induced in vivo and in vitro by microcystin-LR, a hepatotoxin from the blue-green alga, *Microcystis aeruginosa*. *Vet Pathol* 28: 259–266.

Horecka, M. , and Komarek, J. (1979) Taxonomic position of three planktonic blue-green algae from the genera *Aphanizomenon* and *Cylindrospermopsis*. *Preslia (Prague)* 51: 289–312.

Hormazabal, V. , Ostensvik, O. , Underdal, B. , and Skulberg, O. M. (2000) Simultaneous determination of the cyanotoxins anatoxin A, microcystin desmethyl-3-RR, LR, RR and YR in water using liquid chromatography-mass spectrometry. *J Chromatogr Relat Technol* 23: 3155–3164.

Hoshimoto, Y. , Kamiya, H. , Yamazato, K. , and Nozawa, K. (1976) Occurrence of a toxic blue-green alga inducing skin dermatitis in Okinawa. In: Ohsaka, A. , Hayashi, K. , and Sawai, Y. (Eds.) *Animal, Plant and Microbial Toxins*. Plenum Publishing, New York, NY, USA. pp. 333–338.

Hotto, A. M. , Satchwell, M. F. , and Boyer, G. L. (2007) Molecular characterization of potential microcystin-producing cyanobacteria in Lake Ontario Embayments and nearshore waters. *Appl Environ Microbiol* 73: 4570–4578.

Hrudey, S. E. , Lambert, T. W. , and Kenefick, S. L. (1994) Health risk assessment of microcystins in drinking water supplies. In: *Toxic Cyanobacteria-a Global Perspective*. Australian Centre for Water Quality Research, Adelaide, Australia. pp. 7–12.

Hrudey, S. , Burch, S. , Burch, M. , Drikas, M. , Georgy, R. , (1999) Remedial measures. In: Chorus, I. , and Bartram, J. (Eds.), *Toxic Cyanobacteria in Water. A Guide to their Public Health Consequences, Monitoring and Management*. Routledge, London, pp. 275–312.

Huber, C. S. (1972) The crystal structure and absolute configuration of 2,9-diacetyl-9-azabicyclo[4,2,1]non-2,3-ene. *Acta Crystol* 238: 2557–2582.

Hummert, C. , Reichelt, M. , and Luckas, B. (2000) New strategy for the determination of microcystins and diarrhetic shellfish poisoning (DSP) toxins, two potent phosphatases 1 and 2A inhibitors and tumor promoters. *J Anal Chem* 366: 508–513.

Hummert, C. , Reichelt, M. , Weiss, J. , Liebert, H. P. , and Luckas, B. (2001) Identification of microcystins in cyanobacteria from the bleiloch former drinking-water reservoir (Thuringia, Germany). *Chemosphere* 44: 1581–1588.

Humpage, A. R. , and Falconer, I. R. (1999) Microcystin-LR and liver tumor promotion: Effects on cytokinesis, ploidy, and apoptosis in cultured hepatocytes. *Environ Toxicol Water Qual* 14: 61–75.

Humpage, A. R. , Hardy, S. J. , Moore, E. J. , Frosco, S. M. , and Falconer, I. R. (2000) Microcystins (cyanobacterial toxins) in drinking water enhance the growth of aberrant crypt foci in the mouse colon. *J Toxicol Environ Health* 61: 155–165.

Humpage, A. R. , Rositano, J. , Bretag, A. H. , Brown, R. , Baker, P. D. , Nicholson, B. C. , and Steffensen, D. A. (1994) Paralytic shellfish poisons from Australian cyanobacterial blooms. *Aus J Mar Freshwater Res* 45: 761–771.

Huot, R. I. , Armstrong, D. I. , and Chanh, T. C. (1989) In vitro and in situ inhibition of the sodium channel blocker STX by monoclonal antibodies. *J Toxicol Environ Health* 27: 381–393.

Imanishi, S. , Kato, H. , Mizuno, M. , Tsuji, K. , and Harada, K.-I. (2005) Bacterial degradation of microcystins and nodularin. *Chem Res Toxicol* 18: 591–598.

Ishida, K. , and Murakami, M. (2000) Kasumigamide, an antialgal peptide from the cyanobacterium *Microcystis aeruginosa*. *J Org Chem* 65: 5898–5900.

Ishida, K. , Christiansen, G. , Yoshida, W. Y. , Welker, M. , Bonjoch, J. , Hertweck, C. , Börner, T. , Hemscheidt, T. K. , and Dittmann, E. (2007) Biosynthetic pathway and structure analysis of aeruginoside 126A and B, cyanobacterial peptides bearing an unusual 2-carboxy-6-hydroxyoctaindole moiety. *Chem Biol* 14: 565–576.

Ishida, K. , Matsuda, H. , and Murakami, M. (1998) Four new microginins, linear peptides from the cyanobacterium *Microcystis aeruginosa*. *Tetrahedron*. 54: 13475–13484.

Ishida, K. , Okita, Y. , Matsuda, H. , Okino, T. , and Murakami, M. (1999) Aeruginosins, protease inhibitors from the cyanobacterium *Microcystis aeruginosa*. *Tetrahedron*. 55: 10971–10988.

Ishida, K. , Welker, M. , Christiansen, G. , Cadel-Six, S. , Bouchier, C. , Dittmann, E. , Hertweck, C. , and Tandeau de Marsac, N. (2009) Plasticity and evolution of aeruginosin biosynthesis in cyanobacteria. *Appl Environ Microbiol* 75: 2017–2026.

Ishii, H. , Nishijima, M. , and Abe, T. (2004) Characterization of degradation process of cyanobacterial hepatotoxins by a gram-negative aerobic bacterium. *Water Res* 38: 2667–2676.

ISO 20179 (2005) Water Quality: Determination of microcystins-method by solid phase extraction (SPE) and high performance liquid chromatography (HPLC) with ultraviolet (UV) detection. ISO, Geneva, Switzerland.

Iteman, I. , Rippka, R. , Tandeau de Marsac, N. , and Herdman, M. (2002) rDNA analyses of planktonic heterocystous cyanobacteria, including members of the genera *Anabaenopsis* and *Cyanospira*. *Microbiology* 148: 481–496.

Ito, E. , Kondo, F. , Terao, K. , and Harada, K.-I. (1997) Neoplastic nodular formation in mouse liver induced by repeated intraperitoneal injections of microcystin-LR. *Toxicon* 35: 1453–1457.

Jacoby, J. M. , Collier, D. C. , Welch, E. B. , Hardy, F. J. , and Crayton, M. (2000) Environmental factors associated with a toxic bloom of *Microcystis aeruginosa*. *Can J Fish Aquat Sci* 57: 231–240.

James, H. , and Fawell, J. (1991) Detection and Removal of Cyanobacterial Toxins from Freshwaters. Report No. 0211. Foundation of Water Research, Murlow, Buckinghamshire, UK.

James, K. J. , Sherlock, I. R. , and Stack, M. A. (1997) Anatoxin-a in Irish freshwater and cyanobacteria, determined using a new fluorimetric liquid chromatographic method. *Toxicon* 35: 963–971.

Jähnichen, S. , Ihle, T. , Petzoldt, T. , and Benndorf, J. (2007) Impact of inorganic carbon availability on microcystin production by *Microcystis aeruginosa* PCC 7806. *Appl Environ Microbiol* 73: 6994–7002.

Janse, I. , Kardinaal, W. E. A. , Meima, M. , Fastner, J. , Visser, P. M. , and Zwart, G. (2004) Toxic and non-toxic *Microcystis* colonies in natural populations can be differentiated on the basis of rRNA gene internal transcribed spacer diversity. *Appl Environ Microbiol* 70: 3979–3987.

Janse, I. , Kardinaal, W. E. A. , Agterveld, M. K-v. , Meima, M. , Visser, P. M. , and Zwart, G. (2005) Contrasting microcystin production and cyanobacterial population dynamics in two Planktothrix-dominated freshwater lakes. *Environ Microbiol* 7: 1514–1524.

Jochimsen, E. M. , Carmichael, W. W. , An, J. , Cardo, D. M. , Cookson, S. T. , Holmes, C. E. M. , Antunes, B. C. , Liho, D. , Lyra, T. M. , Barreto, V. S. T. , Azevedo, S. M. F. O. , and Jarvis, W. R. (1998) Liver failure and death after exposure to microcystins at a haemodialysis center in Brazil. *New Eng J Med* 338: 873–878.

John, W. , Raynor, M. W. , and Rae, B. (1997) Micellar electrokinetic capillary chromatography of algal toxins. *J High Res Chromatogr* 20: 34–38.

Jones, A. C. , Gerwick, L. , Gonzalez, D. , Dorrestein, P. C. , and Gerwick, W. H. (2009) Transcriptional analysis of the jamaicamide gene cluster from the marine cyanobacterium *Lyngbya majuscula* and identification of possible regulatory proteins. *BMC Microbiol* 9: 247. doi:1186/1471-2180-9-247.

Jones, G. J. , and Orr, P. T. (1994) Release and degradation of microcystin following algicide treatment of a *Microcystis aeruginosa* bloom in a recreational lake, as determined by HPLC and protein phosphatase inhibition assay. *Water Res* 28: 871–876.

Jones, G. J. , Blackburn, S. I. , and Parker, N. S. (2006) A toxic bloom of *Nodularia spumigena* Mertens in Orielton Lagoon, Tasmania. *Aus J Marine Freshwater Res* 45: 787–800.

Jones, G. J. , Bourne, D. G. , Blakeley, R. L. , and Doelle, H. (1994) Degradation of the cyanobacterial hepatotoxin microcystin by aquatic bacteria. *Nat Toxins* 2: 228–235.

Jones, W. W. , and Sauter, S. (2005) Distribution and Abundance of *Cylindrospermopsis raciborskii* in Indiana Lakes and Reservoirs. Office of Water Quality, Indiana Department of Environmental Management, Indianapolis, IN, USA.

Jos, A. , Pichardo, S. , Prieto, A. I. , Repetto, G. , Vazquez, C. M. , Moreno, I. , and Camean, A. M. (2005) Toxic cyanobacterial cells containing microcystins induce oxidative stress in exposed tilapia fish (*Oreochromis* sp.) under laboratory conditions. *Aquat Toxicol* 72: 261–271.

Jung, S.-W. , Baek, K.-H. , and Yu, M.-J. (2005) Treatment of taste and odour material by oxidation and adsorption. *Off-Flavours in the aquatic environment VI. Water Sci Technol* 49: 289–295.

Jungblut, A. D. , Hoeger, S. J. , Mountford, D. , Hitzfeld, B. C. , Dietrich, D. R. , and Neilan, B. A. (2006) Characterization of microcystin production in an Antarctic cyanobacterial mat community. *Toxicon* 47: 271–278.

Kaas, H. , and Henriksen, P. (2000) STXs (PSTs) in Danish Lakes. *Water Res* 34: 2089–2097.

Kaebernick, M. , and Neilan, B. A. (2001) Ecological and molecular investigations of cyanotoxin production. *FEMS Microbiol Ecol* 35: 1–9.

Kaebernick, M. , Dittmann, E. , Borner, T. , and Neilan, B. A. (2002) Multiple alternate transcripts direct the biosynthesis of microcystin, a cyanobacterial nonribosomal peptide. *Appl Environ Microbiol* 68: 449–455.

Kaebernick, M. , Neilan, B. A. , Boerner, T. , and Dittman, E. (2000) Light and the transcriptional response of the microcystin biosynthesis gene cluster. *Appl Environ Microbiol* 66: 3387–3392.

Kaebernick, M. , Rohrlack, T. , Christoffersen, K. , and Neilan, B. A. (2001) A spontaneous mutant of microcystin biosynthesis: Genetic characterization and effect on *Daphnia*. *Environ Microbiol* 3: 669–679.

Kalbe, L. , and Tiess, D. (1964) Entenmassensterben durch *Nodularia wasserbute* kleinen jasmundu dodden auf rugen. *Arch Exp Vet Med* 18: 535–539. Cited from

Carmichael, W. W. , Eschedor, J. T. , Patterson, G. M. L. , and Moore, R. E. (1988) Toxicity and partial structure of a hepatotoxic peptide produced by the cyanobacterium *Nodularia spumigena* Mertens emend. L575 from New Zealand. *Appl Environ Microbiol* 54: 2257–2263.

Karanfil, T. , Kitis, M. , Kilduff, J. , and Wigton, A. (1999) Role of granular activated carbon surface chemistry on the adsorption of organic compounds. 2. Natural organic matter. *Environ Sci Technol* 33: 3225–3233.

Karjalainen, M. , Reinkainen, M. , Lindvall, F. , Spoof, L. , and Meriluto, J. A. O. (2003) Uptake and accumulation of dissolved, radiolabeled nodularin in Baltic Sea zooplankton. *Environ Toxicol* 18: 52–60.

Kaya, K. , and Watanabe, M. M. (1990) Microcystin composition of an axenic clonal strain of *Microcystis viridis*-containing waterblooms in Papanese freshwaters. *J Appl Phycol* 2: 173–178.

Kaya, K. , Mahakhant, A. , Keovara, L. , Sano, T. , Kubo, T. , and Takagi, H. (2002) Spiroidesin, a novel lipopeptide from the cyanobacterium *Anabaena spiroides* that inhibits cell growth of the cyanobacterium *Microcystis aeruginosa*. *J Nat Prod* 65: 920–921.

Kehr, J.-C. , Zilliges, Y. , Springer, A. , Disney, M. D. , Ratner, D. D. , Bouchier, C. , Seeberger, P. H. , Tandeau de Marsac, N. , and Dittmann, E. (2006) A mannan binding lectin is involved in cell-cell attachment in a toxic strain of *Microcystis aeruginosa*. *Mol Microbiol* 59: 893–906.

Keleti, G. , and Sykora, J. L. (1982) Production and properties of cyanobacterial endotoxins. *Appl Environ Microbiol* 43: 104–109.

Keleti, G. , Sykora, J. L. , Libby, E. C. , and Shapiro, M. A. (1979) Composition and biological properties of lipopolysaccharides isolated from *Schizothrix calcicola* (Ag.) Gomont (cyanobacteria). *Appl Environ Microbiol* 38: 471–477.

Kellmann, R. , and Neilan, B. A. (2007) Biochemical characterization of paralytic shellfish toxin biosynthesis in vitro. *J Phycol* 43: 497–508.

Kellmann, R. , Mihali, T. K. , Jeon, Y. J. , Pickford, R. , Pomati, F. , and Neilan, B. A. (2008) Biosynthetic intermediate analysis and functional homology reveal a putative saxitoxin gene cluster in cyanobacteria. *Appl Environ Microbiol* 74: 4044–4053.

Kellmann, R. , Mills, T. , and Neilan, B. A. (2006) Functional modeling and phylogenetic distribution of putative cylindrospermopsin biosynthesis enzymes. *J Mol Evol* 62: 267–280.

Kellmann, R. , Stücken, A. , Orr, R. J. S. , Svendsen, H. M. , and Jakobsen, K. S. (2010) Biosynthesis and molecular genetics of polyketides in marine dinoflagellates. *Mar Drugs* 8: 1011–1048. doi:10.3390/md8041011.

Kemp, A. , and John, J. (2006) Microcystins associated with *Microcystis* dominated blooms in the Southwest wetlands, Western Australia. *Environ Toxicol* 21: 125–130.

Kerr, J. F. R. , Wyllie, A. H. , and Currie, A. R. (1972) Apoptosis: A basic biological phenomenon with wide ranging implications in tissue kinetics. *Br J Cancer* 26: 239–257.

Kfir, R. , Johannsen, E. , and Botes, D. P. (1986) Monoclonal antibody specific for cyanoginosin-LA: Preparation and characterization. *Toxicon* 24: 543–552.

Khan, S. A. , Wickstrom, M. L. , Haschek, W. M. , Schaeffer, D. J. , Ghosh, S. , and Beasley, V. R. (1996) Microcystin-LR and kinetics of cytoskeletal reorganization in hepatocytes, kidney cells, and fibroblasts. *Nat Toxins* 4: 206–214.

Kiviranta, J. , Sivonen, K. , and Niemela, S. I. (1991) Detection of toxicity of cyanobacteria by *Artemia salina* bioassay. *Environ Toxicol Water Qual* 6: 423–436.

Kleinkauf, H. , and von Doehren, H. (1996) A nonribosomal system of peptide biosynthesis. *Eur J Biochem* 236: 335–351.

Kodania, S. , Suzuukia, S. , Ishidaa, K. , and Murakamia, M. (1999) Five new cyanobacterial peptides from water bloom materials of lake Teganuma (Japan). *FEMS Microbiol Lett* 178: 343–348.

Komarek, J. , and Kling, H. (1991) Variation in six planktonic cyanophyte genera in Lake Victoria (East Africa). *Arch Hydrobiol* 88: 21–46.

Komarkova, J. (1998) The tropical planktonic genus *Cylindrospermopsis* (Cyanophytes, Cyanobacteria). In: Azevedo, S. M. F. O. (Ed.) *Anais dos IV Congresso Latino-Americano de Ficologia. II. Reuniao Ibero Americana de Ficologia e VII Reuniao Brasileira de Ficologia. Vol. I, Sao Paulo, Brazil. pp. 327–340.*

Komarkova, J. , Laudares-Silva, R. , and Senna, P. A. C. (1999) Extreme morphology of *Cylindrospermopsis raciborskii* (Nostocales, Cyanobacteria) in the Lagoa do Peri, a freshwater coastal lagoon, Santa Catarina, Brazil. *Arch Hydrobiol (Suppl. 129) Algal Stud* 94: 207–222.

Kondo, F. , Ikai, Y. , Oka, H. , Okumura, M. , Ishikawa, N. , Harada, K.-I. , Matsuura, K. , Murata, H. , and Suzuki, M. (1992a) Formation, characterization, and toxicity of the glutathione and cysteine conjugates of toxic heptapeptide microcystins. *Chem Rev Toxicol* 5: 591–596.

Kondo, F. , Ikai, Y. , Oka, H. , Ishikawa, N. , Watanabe, M. F. , Watanabe, M. , Harada, K.-I. , and Suzuki, M. (1992b) Separation and identification of microcystins in cyanobacteria by frit-fast atom bombardment liquid chromatography/mass spectrometry. *Toxicon* 30: 227–237.

Kondo, F. , Ikai, Y. , Oka, H. , Matsumoto, H. , Yamada, S. , Ishikawa, N. , Tsuji, K. , Harada, K.-I. , Shimada, T. , Oshikata, M. , and Suzuki, M. (1995) Reliable and sensitive method for determination of microcystins in complicated matrices by frit-fast atom bombardment liquid chromatography/mass spectrometry. *Nat Toxins* 3: 41–49.

Kondo, F. , Matsumoto, H. , Yamada, S. , Ishikawa, N. , Ito, E. , Nagata, S. , Ueno, Y. , Suzuki, M. , and Harada, K.-I. (1996) Detection and identification of metabolites of microcystins formed in vivo in mouse and rat livers. *Chem Res Toxicol* 9: 1355–1359.

Kondo, R. , Yoshida, T. , Yuki, Y. , and Shingo, H. (2000) DNA-DNA reassociation among a bloom-forming cyanobacterial genus, *Microcystis*. *Int J Syst Evol Microbiol* 50: 767–770.

Kos, P. , Gorzo, G. , Suranyi, G. , and Borbely, G. (1995) Simple and efficient method for isolation and measurement of cyanobacterial hepatotoxins by plant tests (*Sinapis alba* L.). *Anal Biochem* 225: 49–53.

Koskeniemi, K. , Lyra, C. , Rajaniemi-Wacklin, P. , Jokela, J. , and Sivonen, K. (2007) Quantitative real-time PCR detection of toxic *Nodularia* cyanobacteria in the Baltic Sea. *Appl Environ Microbiol* 73: 2173–2174.

Kotak, B. G. , Kenefick, S. L. , Fritz, D. L. , Rousseaux, C. G. , Prepas, E. E. , and Hrudey, S. E. (1993) Occurrence and toxicological evaluation of cyanobacterial toxins in Alberta lakes and farm dugouts. *Water Res* 27: 495–506.

Kotak, B.G. , Lam, A. K.-Y. , Prepas, E. E. , Holmes, C. F. B. , and Hrudey, S. E. (2000) Role of chemical and physical variables in regulating microcystin-LR concentration in phytoplankton of eutrophic lakes. *Can J Fish Aquat Sci* 57: 1584–1593.

Krishnamurthy, T. , Carmichael, W. W. , and Sarver, E. W. (1986) Toxic peptides from freshwater cyanobacteria (Blue-green algae). I. Isolation, purification and characterization of peptides from *Microcystis aeruginosa* and *Anabaena flos-aquae*. *Toxicon* 24: 865–873.

Krishnamurthy, T. , Szafraniec, L. , Hunt, D. F. , Shabanowitz, J. , Yates, J. R. III., Hauer, C. R. , Carmichael, W. W. , Skulberg, O. , Codd, G. A. , and Missler, S. (1989) Structural characterization of toxic cyclic peptides from blue-green algae by tandem mass spectrometry. *Proc Natl Acad Sci USA* 86: 770–774.

Kuiper-Goodman, T. , Falconer, I. , and Fitzgerald, J. (1999) Human health aspects. In: Chorus, I. , and Bartram, J. (Ed.) *Toxic Cyanobacteria in Water: A Guide to Public Health Consequences, Monitoring and Management. WHO Publ., E. & F. N. Spon, London-New York. pp. 41–111.*

Kull, T. P. , Backlund, P. H. , Karlsson, K. M. , and Meriluto, J. A. (2004) Oxidation of the cyanobacterial hepatotoxin microcystin-LR by chlorine dioxide: Reaction kinetics, characterization, and toxicity of reaction products. *Environ Sci Toxicol* 38: 6025–6031.

Kull, T. P. , Sjövall, O. T. , Tammenkoski, M. K. , Backlund, P. H. , and Meriluto, J. A. (2006) Oxidation of the cyanobacterial hepatotoxin microcystin-LR by chlorine dioxide: Influence of natural organic matter. *Environ Sci Technol* 40: 1504–1510.

Kurmayer, R. , and Christiansen, G. (2009) The genetic basis of toxin production in cyanobacteria. *Freshwater Rev* 2: 31–50.

Kurmayer, R. , and Juettner, F. (1999) Strategies for the co-existence of zooplankton with the toxic cyanobacterium *Planktothrix rubescens* in lake Zurich. *J Plankton Res* 21: 659–683.

Kurmayer, R. , and Kutzenberger, T. (2003) Application of real-time PCR for quantification of the toxic cyanobacterium *Microcystis* sp. *Appl Environ Microbiol* 69: 6723–6730.

Kurmayer, R. , Christiansen, G. , Fastner, J. , and Boemer, T. (2004) Abundance of active and inactive microcystin genotypes in populations of the toxic cyanobacterium *Planktothrix* spp. *Environ Microbiol* 6: 831–841.

Kurmayer, R. , Christiansen, G. , Gumpenberger, M. , and Fastner, J. (2005) Genetic identification of microcystin ecotypes in toxic cyanobacteria of the genus *Planktothrix*. *Microbiology* 151: 1525–1533.

Kusumi, T. , Ooi, T. , Watanabe, M. M. , Takahasi, H. , and Kakisawa, H. (1987) Cyanoviridin RR, a toxin from the cyanobacterium (blue-green alga) *Microcystis viridis*. *Tetrahedron Lett* 28: 4695–4698.

Kyselkova, I. , and Marsalek, B. (2000) Using of *Daphnia pulex*, *Artemia salina* and *Tubifex tubifex* for cyanobacterial microcystins toxicity detection. *Biologia* 55: 637–643.

Lagos, N. , Onodera, H. , Zagatto, P. A. , Andrinolo, D. , Azevedo, S. M. , and Oshima, Y. (1999) The first evidence of paralytic shellfish toxins in the freshwater cyanobacterium *Cylindrospermopsis raciborskii*, isolated from Brazil. *Toxicon* 37: 1359–1373.

Lahti, K. , Ahtiainen, J. , Rapala, J. , Sivonen, K. , and Niemela, S. I. (1995) Assessment of rapid bioassays for detecting cyanobacterial toxicity. *Lett Appl Microbiol* 21: 109–114.

Lahti, K. , Rapala, J. , Faerdig, M. , Niemela, M. , and Sivonen, K. (1997) Presence of cyanobacterial hepatotoxin, microcystin-LR in particulate material and dissolved in lake water. *Water Res* 31: 187–195.

Lam, A. K. Y. , Prepas, E. E. , Spink, D. , and Hrudey, S. E. (1995) Chemical control of hepatotoxic phytoplankton blooms: implications for human health. *Water Res* 29: 1845–1854.

Lambert, T. W. , Boland, M. P. , Holmes, C. F. B. , and Hrudey, S. E. (1994) Quantitation of the microcystin hepatotoxins in water at environmentally relevant concentrations with the protein phosphatase bioassay. *Environ Sci Technol* 28: 753–755.

Lampert, W. (1981) Inhibitory and toxic effects of blue-green algae on *Daphnia*. *Int Revue Ges Hydrobiol* 66: 285–298.

Lampert, W. (1987) Laboratory studies on zooplankton-cyanobacteria interactions. *New Zealand J Mar Freshwater Res* 21: 483–490.

Lanaras, T. , and Cook, C. M. (1994) Toxin extraction from an *Anabaenopsis milleri*-dominated bloom. *Sci Technol Environ* 142: 163–169.

Lang, J. D. , and Haselkorn, R. (1989) Isolation, sequence and transcription of the gene encoding the photosystem II chlorophyll-binding protein phosphatase 1 and 2A from both mammals and higher plants. *Plant Mol Biol* 13: 441–457.

Langlais, B. , Reckhow, D. A. , and Brink, D. R. (1991) *Ozone in Water Treatment. Application and Engineering*. CO/Chelesa, MI, American Water Works Association Research Foundation, Lewis Publishers.

Lankoff, A. , and Banasik, A. (2001) The effect of cyanobacterial toxins on the stability of intracellular membranes. *Cell Biol Mol Lett* 6: 410

Lankoff, A. , Banasik, A. , and Nowak, M. (2002) Protective effect of melatonin against nodularin-induced oxidative stress. *Arch Toxicol* 76: 158–165.

Lankoff, A. , Banasik, A. , Obe, G. , Deperas, M. , Kuzminski, K. , Tarczynska, M. , Jurczak, T. , and Wojcik, A. (2003). Effect of microcystin-LR and cyanobacterial extract from Polish reservoir of drinking water on cell cycle progression, mitotic spindle and apoptosis in CHO-K1 cells. *Toxicol Appl Pharmacol* 189: 204–212.

Lankoff, A. , Bialczyk, J. , Dziga, D. , Carmichael, W. W. , Gradzka, I. , Lisowska, H. , Kuszewski, T. , Gozdz, S. , Piorun, I. , and Wojcik, A. (2006) The repair of gamma-irradiation-induced DNA damage is inhibited by microcystin-LR, the PP1 and PP2A phosphatase inhibitor. *Mutagenesis* 21: 83–90.

Lankoff, A. , Carmichael, W. W. , Grasman, K. A. , and Yuan, M. (2004) The uptake kinetics and immunotoxic effects of microcystin-LR and chicken peripheral blood lymphocytes in vitro. *Toxicology* 204: 23–40.

Lankoff, A. , Krzowski, L. , Glab, J. , Banasik, A. , Lisowska, H. , Kuszewski, T. , Gozdz, S. , and Wojcik, A. (2004) DNA damage and repair in human peripheral blood lymphocytes following treatment with microcystin-LR. *Mutat Res* 559: 131–142.

Lawton, L. A. , Campbell, D. L. , Beattie, K. A. , and Codd, G. A. (1990) Use of a rapid bioluminescence assay for detecting cyanobacterial microcystin toxicity. *Lett Appl Microbiol* 11: 205–207.

Lawton, L. A. , Cornish, B. J. P. A. , and MacDonald, A. W. R. (1998) Removal of cyanobacterial toxins (microcystins) and cyanobacterial cells from drinking water using domestic water filters. *Water Res* 32: 633–638.

Lawton, L. A. , Edwards, C. , and Codd, G. A. (1994) Extraction and high-performance liquid chromatographic method for the determination of microcystins in raw and treated waters. *Analyst* 119: 1525–1530.

Lawton, L. A. , Edwards, C. , Beattie, K. A. , Pleasance, S. , Dear, D. J. , and Codd, G. A. (1995) Isolation and characterization of microcystins from laboratory cultures and environmental samples of *Microcystis aeruginosa* and from an associated animal toxicosis. *Nat Toxins* 3: 50–57.

Leckoski, N. , Fewer, D. P. , and Sivonen, K. (2009) Wide spread occurrence and lateral gene transfer of the cyanobactin biosynthesis gene cluster in cyanobacteria. *Appl Environ Microbiol* 75: 853–857.

Ledereux, A. , Thomazeau, S. , Catharine, A. , Duval, C. , Yéprémian, C. , Marie, A. , and Bernard, C. (2010) Evidence for saxitoxins production by the cyanobacterium *Aphanizomenon gracile* in a French recreational water body. *Harmful Algae* 10: 88–97.

Lee, T. H. , Chen, Y. M. , and Chou, H. N. (1998) First report of microcystins in Taiwan. *Toxicon* 36: 247–255.

Legrini, O. , Oliveros, E. , and Braun, A. M. (1993) Photochemical processes for water treatment. *Chem Rev* 93: 671–698.

Lehtimaeki, J. , Moisander, P. , Sivonen, K. , and Kononen, K. (1997) Growth, nitrogen fixation, and nodularin production by two Baltic Sea cyanobacteria. *Appl Environ Microbiol* 63: 1647–1656.

Leusch, H. , Pangilinan, R. , Yoshida, W. Y. , Moore, R. E. , and Paul, V. J. (2001) Pitipeptolides A and B, new cyclodepsipeptides from the marine cyanobacterium *Lyngbya majuscula*. *J Nat Prod* 64: 304–307.

Levin, R. E. (1992) Paralytic shellfish toxins: Their origin, characteristics, and methods of detection: A review. *J Food Biochem* 15: 405–417.

Li, W. I. , Berman, F. W. , Yokokawa, F. , Shioiri, T. , Gerwick, W. H. , and Murray, T. F. (2001) Antillatoxin is a marine cyanobacterial toxin that potently activates voltage-gated sodium channels. *Proc Natl Acad Sci USA* 98: 7599–7604.

Lim, I. K. , Park, T. J. , Park, S. C. , Yoon, G. , Kwak, C. S. , Lee, M. S. , Song, K. Y. , Choi, Y. K. , and Hyun, B. H. (2001) Selective left-lobe atrophy by nodularin treatment accompanied by reduced protein phosphatase 1/2a and increased peroxisome proliferation in rat liver. *Int J Cancer* 91: 32–40.

Lin, J. R. , and Chu, F. S. (1994a) Kinetics of distribution of microcystin-LR in serum and liver cytosol of mice: An immunochemical analysis. *J Agric Food Chem* 42: 1035–1040.

Lin, J. R. , and Chu, F. S. (1994b) In vitro neutralization of the inhibitory effect of microcystin-LR to protein phosphatase 2A by antibody against the toxin. *Toxicon* 32: 605–613.

Li, R. , Carmichael, W. W. , Brittain, S. , Eaglesham, G. K. , Shaw, G. R. , Liu, Y. , and Watanabe, M. M. (2001) First report of the cyanotoxins cylindrospermopsin and deoxycylindrospermopsin from *Raphidiopsis curvata* (cyanobacteria). *J Phycol.* 37: 1121–1126.

Lindstrom, E. (1976) Et utbrud af algeforgiftning blandt hunde. *Dansk Veterinaertidsskr* 59: 637–641 (In Danish) Cited from

Sivonen, K. , Kononen, K. , Carmichael, W. W. , Dahlem, A. M. , Rinehart, K. L. , Kiviranta, J. , Niemela, S. I. (1989) Occurrence of the hepatotoxic cyanobacterium *Nodularia spumigena* in the Baltic Sea and structure of the toxin. *Appl Environ Microbiol* 55: 1990–1995.

Lippy, E. C. , and Erb, J. (1976) Gastrointestinal illness at Sewickley, PA. *J Am Water Works Assoc* 68: 606–610.

Liu, B.-H. , Yu, F.-Y. , Huang, X. , and Chu, F. F. (2000) Variation of microcystin content of *Microcystis aeruginosa* relative to medium N:P ratio and growth stage. *J Appl Microbiol* 89: 323–329.

Liu, Y. , Chen, W. , Li, D. , Shen, Y. , Liu, Y. , and Song, L. (2006) Analysis of paralytic shellfish toxins in *Aphanizomenon DC-1* from Lake Dianchi, China. *Environ Toxicol* 21: 289–295.

Liu, Y. , Song, L. , Li, X. , Liu, T. (2002) The toxic effects of microcystin-LR on embryo-larval and juvenile development of loach, *Misgurnus mizolepis* Gunthe. *Toxicon* 40: 395–399.

Long, B. M. , Jones, G. J. , and Orr, P. T. (2001) Cellular microcystin content in N-limited *Microcystis aeruginosa* can be predicted from growth rate. *Appl Environ Microbiol* 67: 278–283.

Looper, R. E. , Runnegar, M. T. C. , and Williams, R. W. (2005) Synthesis of putative structure of 7-deoxycylindrospermopsin: C7 oxygenation is not required for the inhibition of protein synthesis. *Angewandte Chemie* 44: 3879–3881.

Luesch, H. , Yoshida, W. Y. , Moore, R. E. , and Paul, V. J. (1999) Lybgyastatin 2 and norlyngbyastatin 2, analogues of dolastatin G and nordolastatin G from the marine cyanobacterium *Lyngbya majuscula*. *J Nat Prod* 62: 1702–1706.

Lukac, M. , and Aegerter, R. (1993) Influence of trace metals on growth and toxin production of *Microcystis aeruginosa*. *Toxicon* 31: 293–305.

Luukkainen, R. , Namikoshi, M. , Sivonen, K. , Rinehart, K. L. , and Niemela, S. I. (1994) Isolation and identification of 12 microcystins from four strains and two bloom samples of *Microcystis* spp.: Structure of a new hepatotoxin. *Toxicon* 32: 133–139.

Luukkainen, R. , Sivonen, K. , Namikoshi, M. , Faerdig, M. , Rinehart, K. L. , and Niemela, S. I. (1993) Isolation and identification of eight microcystins from thirteen *Oscillatoria* strains and structure of a new microcystin. *Appl Environ Microbiol* 59: 2204–2209.

Lyra, C. , Hantula, J. , Vainio, E. , Rapala, J. , Rouhiainen, L. , and Sivonen, K. (1997) Characterization of cyanobacteria by SDS-PAGE of whole-cell proteins and PCR/RFLP of the 16S rRNA gene. *Arch Microbiol* 168: 176–184.

Lyra, C. , Laamanen, M. , Lehtimaeki, J. M. , Surakka, A. , and Sivonen, K. (2005) Benthic cyanobacteria of the genus *Nodularia* are non-toxic, without gas vacuoles, able to glide and genetically more diverse than planktonic *Nodularia*. *Int J Syst Evol Microbiol* 55: 555–568.

Ma, B. , Chen, Y. , Hao, H. , Wang, B. , Lv, H. , and Zhang, G. (2005) Influence of ultrasonic field on microcystins produced by bloom forming algae. *Colloids Surf Biointerfaces* 41: 197–201.

Maatouk, I. , Bouaicha, N. , Fontan, D. , and Levi, Y. (2002) Seasonal variation of microcystin concentration in Saint-Caprais reservoir (France) and their removal in a small full scale treatment plant. *Water Res* 36: 2891–2897.

MacKintosh, C. , and MacKintosh, R. W. (1994) The inhibition of protein phosphatases by toxins: implications for health and an extremely sensitive and rapid bioassay for toxin detection. In: Codd, G. A. , Jefferies, T. M. , Keevil, C. W. , and Potter, E. (Eds.) *Detection Methods for Cyanobacterial Toxins*. Royal Society of Chemistry, Cambridge, UK. pp. 90–99.

MacKintosh, C. , Beattie, K. A. , Klumpp, S. , Cohen, P. , and Codd, G. A. (1990) Cyanobacterial microcystin-LR is a potent and specific inhibitor of protein phosphatases 1 and 2A from both mammals and higher plants. *FEBS Lett* 264: 187–192.

MacKintosh, R. W. , Dalby, K. N. , Campbell, D. G. , Cohen, P. T. , Cohen, P. , and MacKintosh, C. (1995) The cyanobacterial toxin microcystin binds covalently to cysteine-273 on protein phosphatase 1. *FEBS Lett* 371: 236–240.

MacMillan, J. B. , and Molinski, T. F. (2002) Lobocyclamide B from *Lyngbya confervoides*. Configuration and asymmetric synthesis of beta-hydroxy-alpha-amino acids by (-)-aspartate-mediated aldol addition. *Org Lett* 4: 1883–1886.

Magalhaes, V. F. , Soares, R. M. , and Azevedo, S. M. F. O. (2001) Microcystin contamination in fish from the Jacarepagua Lagoon (Rio de Janeiro, Brazil): Ecological implication and human health risk. *Toxicon* 39: 1077–1085.

Mahmood, N. A. , and Carmichael, W. W. (1986a) The pharmacology of anatoxin-a(s), a neurotoxin produced by the freshwater cyanobacterium *Anabaena flos-aquae* NRC-17. *Toxicon* 24: 425–434.

Mahmood, N. A. , and Carmichael, W. W. (1986b) Paralytic shellfish poisons produced by the freshwater cyanobacterium *Aphanizomenon flos-aquae* NH5. *Toxicon* 24: 175–186.

Mahmood, N. A. , and Carmichael, W. W. (1987) Anatoxin-a(s), an anticholinesterase from the cyanobacterium *Anabaena flos-aquae* NCR-525-17. *Toxicon* 25: 1221–1227.

Main, D. C. , Berry, P. H. , Peet, R. L. , and Robertson, J. P. (1977) Sheep mortalities with the blue-green alga *Nodularia spumigena*. *Aus Vet J* 53: 578–581.

Majsterek, I. , Sicinska, P. , Tarczyska, M. , Zalewski, M. , and Walter, Z. (2004) Toxicity of microcystin from cyanobacteria growing in a source of drinking water. *Toxicol Pharmacol* 139: 175–179.

Makowski, A. , and Wardas, W. (2001) Photocatalytic degradation of toxins secreted to water by cyanobacteria and unicellular algae and photocatalytic degradation of the cells of selected microorganisms. *Curr Topics Biochem* 25: 19–25.

Mankiewicz, J. , Komarkova, J. , Izydorczyk, K. , Jurczak, T. , Tarczyska, M. , and Zalewski, M. (2005) Hepatotoxic cyanobacterial blooms in the lakes of northern Poland. *Environ Toxicol* 20: 499–506.

Mankiewicz, J. , Walter, Z. , Tarczyska, M. , Fladmark, K. E. , Doskeland, S. O. , and Zalewski, M. (2000) Apoptotic effect of cyanobacterial blooms collected from water reservoirs. *Polish J Occupational Med Environ Health* 13: 335–344.

Mankiewicz, J. , Walter, Z. , Tarczyska, M. , Fladmark, K. E. , Doskeland, S. O. , and Zalewski, M. (2001) Apoptotic effect of cyanobacterial extract on rat hepatocytes and human lymphocytes. *Environ Toxicol Water Qual* 3: 225–233.

Mankiewicz, J. , Walter, Z. , Tarczyska, M. , Palyvoda, O. , Wojtysiak-Staniaszczyk, M. , and Zalewski, M. (2002) Genotoxicity of cyanobacterial extracts containing microcystins from Polish water reservoirs as determined by SOS chemostat and comet assay. *Environ Toxicol* 17: 341–350.

Marner, F. J. , and Moore, R. E. (1977) Majusculamides A and B, two epimeric lipopeptides from *Lyngbya majuscula* Gomont. *J Org Chem* 42: 2815–2819.

Marsalek, B. , and Blaha, L. (2004) Comparison of 17 biotests for detection of cyanobacterial toxicity. *Environ Toxicol* 19: 310–317.

Marsalek, B. , Blaha, L. , Turanek, J. , and Neca, J. (2001) Microcystin-LR and total microcystins in cyanobacterial blooms in the Czech Republic 1993–1998. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes and Consequences*. Springer, Berlin, Germany. pp. 56–62.

Mason, C. P. , Edwards, K. R. , Carlson, R. E. , Pignatello, J. , Gleason, P. K. , and Wood, J. M. (1982) Isolation of chlorine-containing antibiotic from the freshwater cyanobacterium *Scytonema hofmanni*. *Science* 215: 400–402.

Mastin, B. J. , Rodgers, Jr., J. H. , and Deardorff, T. L. (2002) Risk evaluation of cyanobacteria-dominated algal blooms in a North Louisiana reservoir. *J Aquat Ecosys Stress and Recovery* 9: 103–114.

Mathys, W. , and Surholt, B. (2004) Analysis of microcystins in freshwater samples using high performance liquid chromatography and an enzyme-linked immunosorbent assay. *Int J Hyg Environ Health* 207: 601–605.

Matsunaga, H. , Harada, K.-I. , Senma, M. , Ito, Y. , Yasuda, N. , Ushida, S. , and Kimura, Y. (1999) Possible cause of unnatural mass death of wild birds in a pond in Nishinomiya, Japan: Sudden appearance of toxic cyanobacteria. *Nat Toxins* 7: 81–84.

Matsunaga, S. , Moore, R. E. , Niemczura, W. P. , and Carmichael, W. W. (1989) Anatoxin-a(s): A potent anticholinesterase from *Anabaena flos-aquae*. *J Am Chem Soc* 111: 8021–8023.

Matthiensen, A. , Beattie, K. A. , Yunes, J. S. , Kaya, K. , and Codd, G. A. (2000) [D-Leu]microcystin-LR, from the cyanobacterium *Microcystis* RST 9501 and from a *Microcystis* bloom in the Patos Lagoon estuary, Brazil. *Phytochemistry* 55: 383–387.

Maynes, J. T. , Luu, H. A. , Cherney, M. M. , Andersen, R. J. , Williams, D. , Holmes, C. F. , and James, M. N. (2006) Crystal structures of protein phosphatase-1 bound to motuporin and dihydromicrocystin-LA: Elucidation of the mechanism of enzyme inhibition by cyanobacterial toxins. *J Mol Biol* 356: 111–120.

Mazmouz, R. , Chapuis-Hugon, F. , Mann, S. , Pichon, V. , Méjean, A. , and Ploux, O. (2010) Biosynthesis of cylindrospermopsin and 7-epicylindrospermopsin in *Oscillatoria* sp. PCC 6506. Identification of the *cyr* gene cluster and toxin analysis. *Appl Environ Microbiol* 76: 4943–4949. doi:10.1128/AEM.00717–10.

Mazur, H. , and Plinski, M. (2001) Stability of cyanotoxins, microcystin-LR and nodularin in seawater and BG-11 medium of different salinity. *Oceanologia* 43: 329–339.

Mazur-Marzec, H. (2006) Characterization of phycotoxins produced by cyanobacteria. *Oceanol Hydrobiol Stud* 35: 85–109.

Mazur-Marzec, H. , Meriluto, J. , Plinski, M. , and Szafranek, J. (2006) Characterization of nodularin variants in *Nodularia spumigena* from the Baltic Sea using liquid chromatography/mass spectrometry/mass spectrometry. *Rapid Commun Mass Spectrom* 20: 2023–2032.

Mazyck, D. , and Cannon, F. (2000) Overcoming calcium catalysis during the thermal reactivation of granular activated carbon. Part I. Steam-curing plus ramped-temperature N₂ treatment. *Carbon* 38: 1785–1799.

Mazyck, D. , and Cannon, F. (2002) Overcoming calcium catalysis during the thermal reactivation of granular activated carbon. Part II. Variation of steam curing reactivation parameters. *Carbon* 40: 241–252.

Mbedi, S. , Welker, M. , Fastner, J. , and Wiedner, C. (2005) Variability of the microcystin synthetase gene cluster in the genus *Planktothrix* (*Oscillatoriales*, *Cyanobacteria*). *FEMS Microbiol Lett* 245: 299–306.

McCafferty, J. , Griffiths, A. D. , Winter, G. , and Chiswell, D. J. (1990) Phage antibodies: Filamentous phage displaying antibody variable domains. *Nature (London)* 348: 552–554.

McDaniel, R. , Ebert-Khosla, S. , Hopwood, D. A. , and Khosla, C. (1993) Engineered biosynthesis of novel polyketides. *Science* 262: 1546–1557.

McDermott, C. M. , Nho, C. W. , Howard, W. , and Holton, B. (1998) The cyanobacterial toxin, microcystin-LR, can induce apoptosis in a variety of cell types. *Toxicon* 36: 1981–1996.

McDermott, C. M. , Feola, R. , and Plude, J. (1995) Detection of cyanobacterial toxins (microcystins) in waters of northeastern Wisconsin by a new immunoassay technique. *Toxicon* 33: 1433–1442.

McElhiney, J. , and Lawton, L. A. (2005) Detection of the cyanobacterial hepatotoxins microcystins. *Toxicol Appl Pharmacol* 203: 219–230.

McElhiney, J. , Drever, M. , Lawton, L. A. , and Porter, A. J. (2002) Rapid isolation of a single-chain antibody against the cyanobacterial toxin microcystin-LR by phage display and its use in the immunoaffinity concentration of microcystins from water. *Appl Environ Microbiol* 68: 5288–5295.

McElhiney, J. , Lawton, L. A. , and Porter, A. J. (2000) Detection and quantification of microcystins (cyanobacterial hepatotoxins) with recombinant antibody fragments isolated from a naïve human phage display library. *FEMS Microbiol Lett* 193: 83–88.

McGregor, G. B. , and Fabbro, L. D. (2000) Dominance of *Cylindrospermopsis raciborskii* (*Nostocales*, *Cyanoprokaryota*) in Queensland tropical and subtropical reservoirs: Implications for monitoring and management. *Lakes Reservoirs: Research Management* 5: 195–205.

McGregor, D. P. , Molloy, P. E. , Cunningham, C. , and Harris, W. J. (1994) Spontaneous assembly of bivalent single-chain antibody fragments in *Escherichia coli*. *Mol Immunol* 31: 219–226.

Méjean, A. , Mann, S. , Maldiney, T. , Vassiliadis, G. , Lequin, O. , and Ploux, O. (2009) Evidence that biosynthesis of neurotoxic alkaloids anatoxin-a and homoanatoxin-a in the cyanobacterium *Oscillatoria* PCC 6506 occurs on a modular polyketide synthase initiated by 1-proline. *J Am Chem Soc* 131: 7512–7513.

Méjean, A. , Mazmouz, R. , Mann, S. , Calteau, A. , Médigue, C. , and Ploux, O. (2010) The genome sequence of the cyanobacterium *Oscillatoria* sp. PCC 6506 reveals several gene clusters responsible for the biosynthesis of toxins and secondary metabolites. *J Bacteriol* 192: 5264–5265. doi:10.1128/JB.00704-10

Meriluto, J. (1997) Chromatography of microcystins. *Anal Chim Acta* 352: 298.

Meriluto, J. A. , and Eriksson, J. E. (1988) Rapid analysis of peptide toxins in cyanobacteria. *J Chromatogr* 438: 93–99.

Meriluto, J. A. , Harmala-Brasken, A.-S. , Eriksson, J. , Toivola, D. , and Lindhol, T. (1996) Choosing analytical strategy for microcystins. *Phycologia* 35 (Suppl 6): 125–132.

Meriluto, J. A. , Nygard, S. E. , Dahlem, A. M. , and Eriksson, J. E. (1990) Synthesis, organotropism and hepatocellular uptake of two tritium-labeled epimers of dihydromicrocystin-LR, a cyanobacterial peptide toxin analog. *Toxicon* 28: 1439–1446.

Metcalfe, J. S. , and Codd, G. A. (2000) Microwave oven and boiling water bath extraction of hepatotoxins from cyanobacterial cells. *FEMS Microbiol Lett* 184: 241–246.

Metcalfe, J. S. , and Codd, G. A. (2004) *Cyanobacterial Toxins in the Water Environment*. Foundation for Water Research, UK. pp. 1–36.

Metcalfe, J. S. , Bell, S. G. , and Codd, G. A. (2001) Colorimetric immuno-protein phosphatase inhibition assay for specific detection of microcystins and nodularins of cyanobacteria. *Appl Environ Microbiol* 67: 904–909.

Mez, K. , Beattie, K. A. , Codd, G. A. , Hanselmann, K. , Hauser, B. , Naegeli, H. , and Preisig, H. R. (1997) Identification of a microcystin in benthic cyanobacteria linked to cattle deaths on alpine pastures in Switzerland. *Eur J Phycol* 32: 111–117.

Mez, K. , Hanselmann, K. , Naegeli, H. , and Preisig, H. R. (1996) Protein-phosphatase-inhibiting activity in cyanobacteria from alpine lakes in Switzerland. *Phycologia* (Suppl) 35: 133–139.

Mihali, T. K. , Carmichael, W. W. , and Neilan, B. A. (2011) A putative gene cluster from a *Lyngbya wollei* bloom that encodes paralytic shellfish toxin biosynthesis. *PLoS ONE* 6: e14657. doi:10.1371/journal.pone.0014657

Mihali, T. K. , Kellmann, R. , Muenchhoff, J. , Barrow, K. D. , and Neilan, B. A. (2008) Characterization of the gene cluster responsible for cylindrospermopsin biosynthesis. *Appl Environ Microbiol* 74: 716–722.

Mihali, T. K. , Kellmann, R. , and Neilan, B. A. (2009) Characterization of the paralytic shellfish toxin biosynthesis gene clusters in *Anabaena circinalis* AWQC131C and *Aphanizomenon* sp. NH-5. *BMC Biochemistry* 10: 8. doi:10.1186/1471–2091-10-8

Mikalsen, B. , Boison, G. , Skulberg, O. M. , Fastner, J. , Davies, W. , Gabrielsen, T. M. , Rudi, K. , and Jakobsen, K. S. (2003) Natural variation in the microcystin synthetase operon *mcvABC* and impact on microcystin production in *Microcystis* strains. *J Bacteriol* 185: 2774–2785.

Mikhailov, A. , Harmala-Brasken, A. S. , Meriluto, J. , Sorokina, Y. , Dietrich, D. , and Eriksson, J. E. (2001) Production and specificity of mono and polyclonal antibodies against microcystins conjugated through N-methylhydroalanine. *Toxicon* 39: 477–483.

Miller, M. J. , and Fallowfield, H. J. (2001) Degradation of cyanobacterial hepatotoxins in batch experiments. *Water Sci Technol* 43: 229–232.

Miller, M. J. , Critchley, M. M. , Hutson, J. , and Fallowfield, H. J. (2001a) The adsorption of hepatotoxins from water on to soil during batch studies. *Water Res* 35: 1461–1468.

Miller, M. J. , Hutson, J. , and Fallowfield, H. J. (2001b) An overview of the potential for removal of cyanobacterial hepatotoxin from drinking water by riverbank filtration. *Environ Health* 1: 82–93.

Milutinovi, A. , Sedmak, B. , Horvat-Znidarsic, I. , and Suput, D. (2002) Renal injuries induced by chronic intoxication with microcystins. *Cell Mol Biol Lett* 7: 139–141.

Mitrovic, S. M. , Pflugmacher, S. , James, K. J. , Furey, A. (2004) Anatoxin-a elicits an increase in peroxidase and glutathione S-transferase activity in aquatic plants. *Aqua Toxicol* 68: 185–192.

Moffitt, M. C. , and Neilan, B. A. (2001) On the presence of peptide synthetase and polyketide synthase genes in the cyanobacterial genus *Nodularia*. *FEMS Microbiol Lett* 196: 207–214.

Moffitt, M. C. , and Neilan, B. A. (2004) Characterization of the nodularin synthetase gene cluster and proposed theory of evolution of cyanobacterial hepatotoxins. *Appl Environ Microbiol* 70: 6353–6362.

Moffitt, M. C. , Blackburn, S. I. , and Neilan, B. A. (2001) rRNA sequences reflect the ecophysiology and define the toxic cyanobacteria of the genus *Nodularia*. *Int J Syst Evol Microbiol* 51: 505–512.

Mohamed, Z. A. (2001) Accumulation of cyanobacterial hepatotoxins by *Daphnia* in some Egyptian irrigation canals. *Ecotoxicol Environ Safety* 50: 4–8.

Mohamed, Z. A. , Carmichael, W. W. , and El-Sharouny, H. M. (1998) Activated carbon removal efficiency of microcystins in an aqueous cell extract of *Microcystis aeruginosa* and *Oscillatoria tenuis* strains isolated from Egyptian freshwaters. *Environ Toxicol* 14: 197–201.

Mohamed, Z. A. , Carmichael, W. W. , and Hussein, A. A. (2003) Estimation of microcystins in the freshwater fish *Oreochromis niloticus* in an Egyptian fish farm containing a *Microcystis* bloom. *Environ Toxicol* 18: 137–141.

Moikeha, S. N. , and Chu, G. W. (1971) Dermatitis-producing alga *Lyngbya majuscula* Gomont in Hawaii. II. Biological properties of the toxic factor. *J Phycol* 7: 8–13.

Molica, R. , Onodera, H. , Garcia, C. , Rivas, M. , Andrinolo, D. , Nascimento, S. , Meguro, H. , Oshima, Y. , Azevedo, S. , and Lagos, N. (2002) Toxins in the freshwater cyanobacterium *Cylindrospermopsis raciborskii* (Cyanophyceae) isolated from Tabocas reservoir in Caruaru, Brazil, including demonstration of a new STX analogue. *Phycologia* 41: 606–611.

Moore, B. S. , Ohtani, I. , de Koning, C. B. , Moore, R. E. , and Carmichael, W. W. (1992) Biosynthesis of anatoxin-a(s). Origin of the carbons. *Tetrahedron Lett* 33: 6595–6598.

Moore, R. E. (1977) Toxins from blue-green algae. *BioScience* 27: 797–802.

Moore, R. E. (1996) Cyclic peptides and depsipeptides from cyanobacteria: A review. *J Ind Microbiol* 16: 134–143.

Moore, R. E. , Chen, J. L. , Moore, B. S. , Patterson, G. M. L. , and Carmichael, W. W. (1991) Biosynthesis of microcystin-LR. Origin of the carbons in the Adda and Masp units. *J Am Chem Soc* 113: 5083.

Moore, R. E. , Ohtani, I. , Moore, B. S. , de Koning, C. B. , Yoshida, W. Y. , Runnegar, M. T. , and Carmichael, W. W. (1993) Cyanobacterial toxins. *Gazzatta Chimica Italiana* 123: 329–336.

Moreno, I. M. , Pereira, P. , Franca, S. , and Camean, A. (2004) Toxic cyanobacteria strains isolated from blooms in the Guadiana River (southwestern Spain). *Biol Res* 37: 405–417.

Morrison, K. F. , Parkin, G. , and Codd, G. A. (2006) Optimization of anabaenopeptin extraction from cyanobacteria and the effect of methanol on laboratory manipulation. *Peptides* 27: 10–17.

Mouchet, P. , and Bonnellye, V. (1998) Solving algae problems: French expertise and world-wide applications. *J Water SRT – Aqua* 47: 125–141.

Mountfort, D. O. , Holland, P. , and Sprosen, J. (2005) Method for detecting classes of microcystins by combination of protein phosphatase inhibition assay and ELISA: Comparison with LC-MS. *Toxicon* 45: 199–206.

Moustafa, A. , Loram, J. E. , Hackett, J. D. , Andersen, O. M. , Plumley, F. G. , and Bhattacharya, D. (2009) Origin of STX biosynthetic genes in cyanobacteria. *PLoS ONE* 4: e5758. doi: 10.1371/journal.pone.0005758

Mulligan, M. E. , and Haselkorn, R. (1989) Nitrogen fixation (nif) genes of the cyanobacterium *Anabaena* sp. strain PCC 7120: The nifB-*fdxN*-*nifS*-*nifU* operon. *J Biol Chem* 264: 19200–19207.

Mynderse, J. S. , Moore, R. E. , Kashiwagi, M. , and Norton, T. R. (1977) Antileukemia activity in the oscillatoriaceae: Isolation of debromoaplysiatoxin from *Lyngbya*. *Science* 196: 538–540.

Nagata, S. , Soutome, H. , Tsutsumi, T. , Hasegawa, A. , Sekijima, M. , Sugamata, M. , Harada, K. , Suganuma, M. , and Ueno, Y. (1995) Novel monoclonal antibodies against microcystin and their protective activity for hepatotoxicity. *Nat Toxins* 3: 78–86.

Nagle, D. G. , Paul, V. J. , and Roberts, M. A. (1996) Y paoamide, a new broadly acting feeding deterrent from the marine cyanobacterium *Lyngbya majuscula*. *Tetrahedron Lett* 37: 6263–6266.

Namikoshi, M. , and Rinehart, K. L. (1996) Bioactive compounds produced by cyanobacteria. *J Ind Microbiol* 17: 373–384.

Namikoshi, M. , Rinehart, K. L. , Sakai, R. , Sivonen, K. , and Carmichael, W. W. (1990) Structure of three new cyclic hepatotoxins produced by the cyanobacterium (blue-green alga) *Nostoc* sp. strain 152. *J Org Chem* 55: 6135–6139.

Namikoshi, M. , Rinehart, K. L. , Sakai, R. , Stotts, R. R. , Dahlem, A. M. , Beasley, V. R. , Carmichael, W. W. , and Evans, W. R. (1992a) Identification of 12 hepatotoxins from a Homer lake bloom of the cyanobacteria *Microcystis aeruginosa*, *Microcystis viridis*, and *Microcystis wesenbergii*: Nine new microcystins. *J Org Chem* 57: 866–872.

Namikoshi, M. , Sivonen, K. , Evans, W. R. , Carmichael, W. W. , Rouhiainen, L. , Luukkainen, R. , and Rinehart, K. L. (1992b) Structure of three new homotyrosine-containing microcystins and a new homophenylalanine variant from *Anabaena* sp. strain 66. *Chem Res Toxicol* 5: 661–666.

Namikoshi, M. , Sivonen, K. , Evans, W. R. , Carmichael, W. W. , Sun, F. , Rouhiainen, L. , Luukkainen, R. , and Rinehart, K. L. (1992c) Two new L-serine variants of microcystin-LR and -RR from *Anabaena* sp. strain 202 A1 and 202 A2. *Toxicon* 30: 1457–1464.

Namikoshi, M. , Sivonen, K. , Evans, W. R. , Sun, F. , Carmichael, W. W. , and Rinehart, K. L. (1992d) Isolation and structure of microcystins from a cyanobacterial water bloom (Finland). *Toxicon* 30: 1473–1479.

Namikoshi, M. , Choi, B. W. , Sakai, R. , Sun, F. , Rinehart, K. L. , Carmichael, W. W. , Evans, W. R. , Cruz, P. , Munro, M. H. G. , and Blunt, J. W. (1994) New nodularin: A general method for structure assignment. *J Org Chem* 59: 2349–2357.

Namikoshi, M. , Sun, F. , Choi, B. W. , Rinehart, K. L. , Carmichael, W. W. , Evans, W. R. , and Beasley, V. R. (1995). Seven more microcystins from Homer lake cells: Application of the general method for structure assignment of peptides containing, -dehydroamino

acid unit(s). *J Org Chem* 60: 3671–3679.

Namikoshi, M. , Yuan, M. , Sivonen, K. , Carmichael, W. W. , Rinehart, K. L. , Rouhiainen, L. , Sun, S. , Brittain, S. , and Otsuki, A. (1998) Seven new microcystins possessing two L-glutamic acid units, isolated from *Anabaena* sp. strain 186. *Chem Res Toxicol* 11: 143–149.

Negri, A. P. , Jones, G. J. , and Hindmarsh, M. (1995) Sheep mortality associated with shellfish poisoning toxins from the cyanobacterium *Anabaena circinalis*. *Toxicon* 33: 1321–1329.

Negri, A. P. , Jones, G. J. , Blackburn, S. I. , Oshima, Y. , and Onodera, H. (1997) Effect of culture and bloom development and of sample storage on paralytic shellfish poisons in the cyanobacterium *Anabaena circinalis*. *J Phycol* 33: 26–35.

Nehring, S. (1993) Mortality of dogs associated with a mass development of *Nodularia spumigena* (Cyanophyceae) in a brackish lake at the German North Sea coast. *J Plankton Res* 15: 867–872.

Neilan, B. A. (1995) Identification and phylogenetic analysis of toxigenic cyanobacteria by multiplex randomly amplified polymorphic DNA PCR. *Appl Environ Microbiol* 61: 2286–2291.

Neilan, B. A. , Jacobs, D. , and Goodman, A. E. (1995) Genetic diversity and phylogeny of toxic cyanobacteria determined by DNA polymorphisms within the phycocyanin locus. *Appl Environ Microbiol* 61: 3875–3883.

Neilan, B. A. , Jacobs, D. , Dot, T. D. , Blackall, L. L. , Hawkins, P. R. , Cox, P. T. , and Goodman, A. E. (1997) rRNA sequences and evolutionary relationship among toxic and non-toxic cyanobacteria of the genus *Microcystis*. *Int J Syst Bacteriol* 47: 693–697.

Neilan, B. A. , Dittmann, E. , Rouhiainen, L. , Baas, R. A. , Schaub, V. , Sivonen, K. , and Borner, T. (1999) Nonribosomal peptide synthesis and toxigenicity of cyanobacteria. *J Bacteriol* 181: 4089–4097.

Neilan, B. A. , Saker, M. L. , Fastner, J. , Tokne, A. , and Burns, B. P. (2003) Phytogeography of the invasive cyanobacterium *Cylindrospermopsis raciborskii*. *Mol Ecol* 12: 133.

Neumann, U. , Campos, V. , Cantarero, S. , Urrutia, H. , Heinze, R. , Weckesser, J. , and Erhard, M. (2000) Co-occurrence of non-toxic (Cyanopeptolin) and toxic (Microcystin) peptides in a bloom of *Microcystis* sp. from a Chilean lake. *Syst Appl Microbiol* 23: 191–197.

Newcombe, G. , Drikas, M. , and Hayes, R. (1997) Influence of characterized natural organic material on activated carbon adsorption. II. Effect on pore volume distribution and adsorption of 2-methylisoborneol. *Water Res* 31: 1065–1073.

Nicholson, B. , and Rositano, J. (1997) Chemical methods for the destruction of cyanobacterial toxins. In: Workshop on cyanobacteria (blue-green algae) and their toxins, Brisbane, Australia, 1997. Australian Water and Wastewater Association, Sydney, Australia.

Nicholson, B. , Rositano, J. , Humpage, A. , and Burch, M. (1993) Removal of algal toxins in water treatment processes. In: 15th AWWA Federal Convention, Gold Coast, Queensland, Australia, Australian Water and Wastewater Association Sydney, Australia pp. 327–331.

Nicholson, B. , Rositano, J. , and Burch, M. D. (1994) Destruction of cyanobacterial peptide hepatotoxins by chlorine and chloramines. *Water Res* 28: 1297–1303.

Nicholson, D. W. , and Thornberry, N. A. (1997) Capsases: killer proteases. *Trends Biochem Sci* 22: 299–306.

Nishihara, H. , Miwa, H. , Watanabe, M. , Nagashima, M. , Yagi, O. , and Takamura, Y. (1997) Random amplification polymorphic DNA (RAPD) analysis for discriminating genotypes of *Microcystis* cyanobacteria. *Biosci Biotech Biochem* 61: 1067–1072.

Nishiwaki, R. , Ohta, T. , Sueoka, E. , Suganuma, M. , Harada, K. , Watanabe, M. F. , and Fujiki, H. (1994) Two significant aspects of microcystin-LR: Specific binding and liver specificity. *Cancer Lett* 83: 283–289.

Nishiwaki-Matsushima, R. , Nishiwaki, S. , Ohta, T. , Yoshizawa, S. , Suganuma, M. , Harada, K.-I. , Watanabe, M. F. , and Fujiki, H. (1991) Structure-function relationships of microcystins, liver tumor promoters, in interaction with protein phosphatase. *Jpn J Cancer Res* 82: 993–996.

Nishizawa, T. , Asayama, M. , and Shirai, M. (2001) Cyclic heptapeptide microcystin biosynthesis requires the glutamate racemase gene. *Microbiology* 147: 1235–1241.

Nishizawa, T. , Asayama, M. , Fujii, K. , Harada, K.-I. , and Shirai, M. (1999) Genetic analysis of the peptide synthetase genes for a cyclic heptapeptide microcystin in *Microcystis* spp. *J Biochem* 126: 520–529.

Nishizawa, T. , Ueda, A. , Asayama, M. , Harada, K. , Ochi, K. , and Shirai, M. (2000) Polyketide synthase gene coupled to the peptide synthetase module involved in biosynthesis of the cyclic heptapeptide microcystin. *J Biochem (Tokyo)* 127: 779–889.

Norris, R. L. , Eaglesham, G. K. , Pierens, G. , Shaw, G. R. , Smith, M. J. , Chiswell, R. K. , Seawright, A. A. , and Moore, M. R. (1999) Stability of cylindrospermopsin, the toxin from the cyanobacterium *Cylindrospermopsis raciborskii*: Effect of pH, temperature, and sunlight on decomposition. *Environ Toxicol* 14: 163–165.

Nuebel, U. , Garcia-Pichel, F. , and Muyzer, G. (1997) PCR primers to amplify 16S rRNA genes from cyanobacteria. *Appl Environ Microbiol* 63: 3327–3332.

Oberemm, A. (2001a) Effects of cyanotoxins on early life stages of fish and amphibians. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes, Consequences*. Springer, Berlin, Germany. pp. 240–248.

Oberemm, A. (2001b) A fish-embryo bioassay for the assessment of cyanobacterial toxicity. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes, Consequences*. Springer, Berlin, Germany. pp. 339–343.

Oberholster, P. J. , Botha, A.-M. , and Grobbelaar, J. U. (2004) *Microcystis aeruginosa*: Source of toxic microcystins in drinking water. *Afr J Biotechnol* 3: 159–168.

Oberholster, P. J. , Botha, A.-M. , and Cloete, T. E. (2006) Toxic cyanobacterial blooms in shallow, artificially mixed urban lake in Colorado, USA. *Lakes & Reservoirs: Research and Management* 11: 111–123.

Oh, H.-M. , Lee, S. J. , Jang, M.-H. , and Yoon, B.-D. (2000) Microcystin production by *Microcystis aeruginosa* in a phosphorus-limited chemostat. *Appl Environ Microbiol* 66: 176–179.

Oh, H.-M. , Lee, S. J. , Kim, J. H. , Kim, H. S. , and Yoon, B. D. (2001) Seasonal variation and indirect monitoring of microcystin concentrations in Daechung Reservoir, Korea. *Appl Environ Microbiol* 67: 1484–1489.

Ohta, T. , Nishiwaki, R. , Yatsunami, J. , Komori, A. , Suganuma, M. , and Fujiki, H. (1992) Hyperphosphorylation of cytokeratin 8 and 18 by microcystin-LR, a new liver tumor promoter, in primary cultured rat hepatocytes. *Carcinogenesis* 13: 2443–2447.

Ohta, T. , Sueoka, E. , Iida, N. , Komori, A. , Suganuma, M. , Nishiwaki, R. , Tatamatsu, M. , Kim, S. J. , Carmichael, W. W. , and Fujiki, H. (1994) Nodularin, a potent inhibitor of protein phosphatase 1 and 2A, is a new environmental carcinogen in male F344 rat liver. *Cancer Res* 54: 6402–6406.

Ohtani, I. , Moore, R. E. , and Runnegar, M. T. C. (1992) Cylindrospermopsin: A potent hepatotoxin from the blue-green alga *Cylindrospermopsis raciborskii*. *J Am Chem Soc* 114: 7942–7944.

Ojanpera, I. , Pelander, A. , Vuori, E. , Himberg, K. , Waris, M. , and Niinivara, K. (1995) Detection of cyanobacterial hepatotoxins by TLC. *J Planar Chromatogr* 8: 69–72.

Okino, T. , Murakami, M. , Haraguchi, R. , Munekata, H. , and Matsuda, H. (1993a) Micropeptins A and B, plasmin and trypsin inhibitors from the blue-green alga *Microcystis aeruginosa*. *Tetrahedron Lett* 34: 8131–8134.

Okino, T. , Matsuda, H. , Murakami, M. , and Yamaguchi, K. (1993b) Microginin, an angiotensin-converting enzyme inhibitor from the blue-green alga *Microcystis aeruginosa*. *Tetrahedron Lett* 34: 501–504.

Okino, T. , Matsuda, H. , Murakami, M. , and Yamaguchi, K. (1995) New microviridins, elastase inhibitors from the blue-green alga *Microcystis aeruginosa*. *Tetrahedron* 51: 10679–10686.

Oksanen, I. , Jokela, J. , Fewer, D. P. , Wahlsten, M. , Rikkinen, J. , and Sivonen K. (2004) Discovery of rare and highly toxic microcystins from lichen-associated cyanobacterium *Nostoc* sp. strain IO-102-I. *Appl Environ Microbiol* 70: 5756–5763.

Onodera, H. , Oshima, Y. , Henriksen, P. , and Yasumoto, T. (1997) Confirmation of anatoxin-a(s) in the cyanobacterium *Anabaena lammermannii* as the cause of bird kills in Danish lakes. *Toxicon* 35: 1645–1648.

Onyewuenyi, N. , and Hawkins, P. (1996) Separation of toxic peptides (microcystins) in capillary electrophoresis, with the aid of organic mobile phase modifiers. *J Chromatogr* 749: 271–278.

Orjala, J. , Nagle, D. G. , Hsu, V. L. , and Gerwick, W. H. (1995) Antillatoxin-an exceptionally ichthyotoxic cyclic lipopeptide from the tropical cyanobacterium *Lyngbya majuscula*. *J Am Chem Soc* 117: 8281–8282.

Osborne, N. J. T. , Webb, P. M. , and Shaw, G. R. (2001) The toxins of *Lyngbya majuscula* and their human and ecological health effects. *Environ Int* 27: 381–392.

Oshima, Y. , Blackburn, S. I. , and Hallegraef, G. M. (1993) Comparative study on paralytic shellfish toxin profiles of the dinoflagellate *Gymnodium catenatum* from three countries. *Mar Biol* 116: 471–476.

Otsuka, S. , Suda, S. , Li, R. H. , Watanabe, M. , Oyaizu, H. , Matsumoto, S. , and Watanabe, M. M. (1998) 16S rDNA sequences and phylogenetic analysis of *Microcystis* strains with and without phycoerythrin. *FEMS Microbiol Lett* 164: 119–124.

Otsuka, S. , Suda, S. , Li, R. H. , Watanabe, M. , Oyaizu, H. , Matsumoto, S. , and Watanabe, M. M. (1999a) Characterization of morphospecies and strains of the genus *Microcystis* (cyanobacteria) for a reconsideration of species classification. *Phycol Res* 47: 189–197.

Otsuka, S. , Suda, S. , Li, R. H. , Watanabe, M. , Oyaizu, H. , Matsumoto, S. , and Watanabe, M. M. (1999b) Phylogenetic relationship between toxic and non-toxic strains of the genus *Microcystis* based on 16S to 23S internal transcribed spacer sequence. *FEMS Microbiol Lett* 172: 15–21.

Ouahid, Y. , Perez-Silva, G. , and Del Campo, F. F. (2005) Identification of potentially toxic environmental *Microcystis* synthetase gene regions. *Environ Toxicol* 20: 235–242.

Oudra, B. , Loudiki, M. , Vasconcelos, V. , Sabour, B. , Sbiyyaa, B. , Oufdou, K. , and Mezrioul, N. (2002) Detection and quantification of microcystins from cyanobacteria strains isolated from reservoirs and ponds in Morocco. *Environ Toxicol* 17: 32–39.

Padisak, J. (2003) Estimation of minimum sedimentary inoculum (akinetes) pool of *Cylindrospermopsis raciborskii*: A morphology and life cycle based method. *Hydrobiologia* 502: 389–394.

Painuly, P. , Perez, R. , Fukai, T. , and Shimizu, Y. (1988) The structure of a cyclic peptide toxin, cyanogenosin-RR, from *Microcystis aeruginosa*. *Tetrahedron Lett* 29: 11–14.

Palenik, B. , and Haselkorn, R. (1992) Multiple evolutionary origins of prochlorophytes, the chlorophyll-containing prokaryotes. *Nature (London)* 355: 265–267.

Papageorgiou, J. , Nicholson, B. C. , Linke, T. A. , and Kapralos, C. (2005) Analysis of cyanobacterial-derived STXs using high performance ion exchange chromatography with chemical oxidation/fluorescence detection. *Environ Toxicol* 5: 549–559.

Park, H.-D. (2001) Cyanotoxins and cyanobacterial blooms in South Korean lakes. In Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes, Consequences*. Springer, Berlin. pp. 68–75.

Park, H.-D. , Sasaki, Y. , Maruyama, T. , Yanagisawa, E. , Hiraishi, A. , and Kato, K. (2001) Degradation of the cyanobacterial hepatotoxin microcystin by a new bacterium isolated from a hypertrophic lake. *Environ Toxicol* 16: 337–343.

Park, H.-D. , Twami, C. , Watanabe, M. F. , Harada, K.-I. , Okino, T. , and Hatashi, H. (1998) Temporal variabilities of the concentrations of intra- and extracellular microcystin and toxic *Microcystis* species in a hypertrophic Lake Suwa, Japan. *Environ Toxicol Water Qual* 13: 61–72.

Park, H.-D. , Watanabe, M. F. , Harada, K. , Hayashi, H. , and Okino, T. (1993) Seasonal variation of *Microcystis* species and toxic heptapeptide microcystins in Lake Suwa. *Environ Toxicol Water Qual* 8: 425–435.

Pearson, L. , Mihali, T. , Moffitt, M. , Kellmann, R. , and Neilan, B. (2010) On the chemistry, toxicology and genetics of the cyanobacterial toxins, microcystin, nodularin, STX, and cylindrospermopsin. *Mar Drugs* 8: 1650–1680.

Pendleton, P. , Wong, S. , Schumann, R. , Levay, G. , Denoyel, R. , and Rouquerol, J. (1997) Properties of activated carbon controlling 2-methylisoborneol adsorption. *Carbon* 35: 1141–1149.

Pereira, P. , Onodera, H. , Andrinolo, D. , Franca, S. , Araujo, F. , Lagos, N. , and Oshima, Y. (2000) Paralytic shellfish toxins in the freshwater cyanobacterium *Aphanizomenon flos-aquae*, isolated from Montargil reservoir, Portugal. *Toxicon* 38: 1689–1702.

Persson, P. , Sivonen, K. , Keto, K. , Kononen, K. , Niemi, M. , and Viljamaa, H. (1984) Potentially toxic blue-green algae (cyanobacteria) in Finnish natural waters. *Aqua Fenn* 14: 147–154.

Phillips, M. J. , Roberts, R. J. , Stewart, J. A. , and Codd, G. A. (1985) The toxicity of the cyanobacterium *Microcystis aeruginosa* to rainbow trout, *Salmo gairdneri* Richardson. *J Fish Dis* 8: 339–344.

Pomati, F. , Kellmann, R. , Cavalieri, R. , Burns, B. P. , and Neilan, B. A. (2006) Comparative gene expression of PSP-toxin-producing and non-toxic *Anabaena circinalis* strains. *Environ Internl* 32: 743–748.

Pomati, F. , Rossetti, C. , Manarolla, G. , Burns, B. P. , and Neilan, B. A. (2004) Interactions between intracellular Na⁺ levels and STX production in *Cylindrospermopsis raciborskii* T3. *Microbiology* 150: 455–461.

Pomati, F. , Sacchi, S. , Rossetti, C. , Giovannardi, S. , Onodera, H. , Oshima, Y. , and Neilan, B. A. (2000) The freshwater cyanobacterium *Planktothrix* sp. FP1: Molecular identification and detection of paralytic shellfish poisoning toxins. *J Phycol* 36: 553–562.

Poon, G. K. , Griggs, L. J. , Edwards, C. , Beattie, K. A. , and Codd, G. A. (1993) Liquid chromatography-electrospray ionization mass-spectrometry of cyanobacterial toxins. *J Chromatogr* 628: 215–233.

Porfirio, Z. , Ribeiro, P. M. , Estevan, C. S. , Ricardo, L. S. , and Santana, A. E. G. (1999) Hepatosplenomegaly caused by an extract of cyanobacterium *Microcystis aeruginosa* bloom collected in the Manguaba Lagoon, Alagoas-Brazil. *Revista de Microbiol* 30: 278–285.

Pouria, S. , de Andrade, A. , Barbosa, J. , Cavalcanti, R. L. , Barreto, V. T. S. , Ward, C. J. , Preiser, W. , Poon, G. K. , Neild, G. H. , and Codd, G. A. (1998) Fatal microcystin intoxication in haemodialysis unit in Caruaru, Brazil. *The Lancet* 352: 21–26.

Premazzi, G. , and Volterra, L. (1993) Microphyte Toxins: A Manual for Toxin Detection, Environmental Monitoring and Therapies to Counteract Intoxications. JRC CEC, Luxembourg.

Prepas, E. E. , and Charette, T. (2003) Worldwide eutrophication of water bodies: Causes, Concerns, Controls. In: Lokar, B. S. (Ed.) Treatise on Geochemistry. Vol. 9. Elsevier, Amsterdam, The Netherlands. pp. 311–331.

Preussel, K. , Stuken, A. , Wiedner, C. , Chorus, I. , and Fastner, J. (2006) First report on cylindrospermopsin producing *Aphanizomenon flos-aquae* (Cyanobacteria) isolated from two German lakes. *Toxicon* 47: 156–162.

Prieto, A. I. , Jos, A. , Pichardo, S. , Moreno, I. , Camean, A. M. , (2006) Differential oxidative stress responses to microcystin-LR and RR in intraperitoneally exposed tilapia fish (*Oreochromis* sp.). *Aquat Toxicol* 77: 314–321.

Princep, M. R. , Caplan, F. R. , Moore, R. E. , Patterson, G. M. L. , Honkanen, R. E. , and Boynton, A. L. (1992) Microcystin-LA from a blue-green alga belonging to the Stigonematales. *Phytochemistry* 31: 1247–1248.

Puschner, B. , Galey, F. D. , Johnson, B. , Dickie, C. W. , Vondy, M. , Francis, T. , and Holstege, D. M. (1998) Blue-green algae toxicosis in cattle. *J Am Vet Med Assoc* 213: 1605–1607.

Pyo, D. , Park, G. , Choi, J. , and Oh, C. (2005) Microcystin detection characteristics of fluorescence immunochromatography and high performance liquid chromatography. *Bull Korean Chem Soc* 26: 268–272.

Rabergh, C. M. I. , Bylund, G. , and Eriksson, J. E. (1991) Histopathological effects of microcystin-LR, a cyclic peptide toxin from the cyanobacterium (blue-green alga) *Microcystis aeruginosa*, on common carp (*Cyprinus carpio* L.). *Aquat Toxicol* 20: 131–146.

Radau, G. , Schermuly, S. , and Fritsche, A. (2003) New cyanopeptide-derived low molecular weight inhibitors of trypsin-like serine proteases. *Arch Pharm* 336: 300–309.

Rantala, A. , Fewer, D. P. , Hisbergues, M. , Rouhiainen, L. , Vaitomaa, J. , Boerner, T. , and Sivonen, K. (2004) Phylogenetic evidence for the early evolution of microcystin synthesis. *Proc Natl Acad Sci USA* 101: 568–573.

Rantala, A. , Rajaniemi-Wacklin, P. , Lyra, C. , Lepistö, L. , Rintala, J. , Mankiewicz-Boczek, J. , and Sivonen, K. (2006) Detection of microcystin-producing cyanobacteria in Finnish Lakes with genus-specific microcystin synthetase gene E (*mcyE*) PCR and associations with environmental factors. *Appl Environ Microbiol* 72: 6101–6110.

Rao, P. V. L. , Battacharya, R. , Parida, M. M. , Jana, A. M. , and Bhaskar, A. S. B. (1998) Freshwater cyanobacterium *Microcystis aeruginosa* (UTEX 2385) induced DNA damage in vivo and in vitro. *Environ Toxicol Pharmacol* 5: 1–6.

Rao, P. V. L. , Battacharya, R. , Gupta, N. , Parida, M. M. , Bhaskar, A. S. B. , and Dubey, R. (2002) Involvement of caspase and reactive oxygen species in cyanobacterial toxin anatoxin-a induced cytotoxicity and apoptosis in rat thymocytes and Vero cells. *Arch Toxicol* 76: 227–235.

Rao, P. V. L. , Gupta, N. , and Jayaraj, R. (2004) Screening of chemoprotectants against cyclic peptide toxin microcystin-LR. *Indian J Pharmacol* 36: 87–92.

Rapala, J. , and Sivonen, K. (1998) Assessment of environmental conditions that favour hepatotoxic and neurotoxic *Anabaena* spp. strains cultured under light limitation at different temperatures. *Microb Ecol* 36: 181–192.

Rapala, J. , Berg, K. A. , Lyra, C. , Niemi, R. M. , Manz, W. , Suomalainen, S. , Paulin, L. , and Lahti, K. (2005) *Paucibacter toxinivorans* gen nov., sp. nov., a bacterium that degrades cyclic cyanobacterial hepatotoxins microcystins and nodularin. *Int J Syst Evol Microbiol* 55: 1563–1568.

Rapala, J. , Sivonen, K. , Lyra, C. , and Niemela, S. I. (1997) Variation of microcystins, cyanobacterial hepatotoxins, in *Anabaena* spp. as a function of growth stimuli. *Appl Environ Microbiol* 63: 2206–2212.

Raziuddin, S. , Siegelman, H. W. , and Tornabene, T. G. (1983) Lipopolysaccharides of the cyanobacterium *Microcystis aeruginosa*. *Eur J Biochem* 137: 333–336.

Reinikainen, M. , Ketola, M. , and Walls, M. (1994) Effects of the concentrations of the toxic *Microcystis aeruginosa* and an alternative food on the survival of *Daphnia pulex*. *Limnol Oceanogr* 39: 424–432.

Repavich, W. M. , Sonzogni, W. C. , Standridge, J. H. , Wedepohl, R. E. , and Meisner, L. F. (1990) Cyanobacteria (blue-green algae) in Wisconsin waters: Acute and chronic toxicity. *Water Res* 24: 225–231.

Repka, S. , Koivula, M. , Jarunpää, V. , Rouhiainen, L. , and Sivonen, K. (2004) Effects of phosphate and light on growth and bioactive peptide production by the cyanobacterium *Anabaena* strain 90 and its anabaenopeptilide mutant. *Appl Environ Microbiol* 70: 4551–4560.

Repka, S. , Mehtonen, J. , Vaitomaa, J. , Saari, I. , and Sivonen, K. (2001) Effects of nutrients on growth and nodularin production of *Nodularia* strain GR8b. *Microb Ecol* 42: 606–613.

Ressom, R. , Soong, F. S. , Fitzgerald, J. , Turczynowicz, L. , El Saadi, O. , Roder, D. , Maynard, T. , and Falconer, I. (1994) Health Effects of Toxic Cyanobacteria (Blue-green algae). Australian National Health and Medical Research Council, Looking Glass Press, Australian Govt. Publication Service, Canberra, Australia. pp. 108.

Reynolds, K. A. (2004) Cyanobacteria: Natural organisms with toxic effects. *Water Conditioning Purif* 3: 78–80.

Rinehart, K. L. , Harada, K.-I. , Namikoshi, M. , Chen, C. , Harvis, C. A. , Munro, M. H. G. , Blunt, J. W. , Mulligan, P. E. , Beasley, B. R. , Dahlem, A. M. , and Carmichael, W. W. (1988) Nodularin, microcystin, and the configuration of Adda. *J Am Chem Soc* 110: 8557–8558.

Rinehart, K. L. , Namikoshi, M. , and Choi, B. W. (1994) Structure and biosynthesis of toxins from blue-green algae (cyanobacteria). *J Appl Phycol* 6: 159–176.

Rinta-Kanto, J. M. , and Wilhelm, S. W. (2006) Diversity of microcystin-producing cyanobacteria in spatially isolated regions of Lake Erie. *Appl Environ Microbiol* 72: 5083–5085.

Rinta-Kanto, J. M. , Ouellette, A. J. A. , Boyer, G. L. , Twiss, M. R. , Bridgeman, T. B. , and Wilhelm, S. W. (2005) Quantification of toxic *Microcystis* spp. during the 2003 and 2004 blooms in Western Lake Erie using quantitative real-time PCR. *Environ Sci Technol* 39: 4198–4205.

Robertson, P. K. J. , Lawton, L. A. , Muench, B. , and Rouzade, J. (1997) Process influencing the destruction of microcystin-LR by TiO₂ photocatalysis. *J Chem Soc Commun* 4: 393–394.

Robillot, C. , Vinh, J. , Puiseux-Dao, S. , and Hennion, M.-C. (2000) Hepatotoxin production kinetics of the cyanobacterium *Microcystis aeruginosa* PCC 7820 as determined by HPLC-Mass spectrometry and protein phosphatase bioassay. *Environ Sci Technol* 34: 3372–3378.

Robinson, N. A. , Pace, J. G. , Matson, C. F. , Dinterman, R. E. , and Pace, J. G. (1989) Characterization of chemically tritiated microcystin-LR and its distribution in mice. *Toxicon* 27: 1035–1042.

Robinson N. A. , Pace, J. G. , Matson, C. F. , Miura, G. A. , and Lawrence, W. B. (1991) Tissue distribution, excretion and hepatic biotransformation of microcystin-LR in mice. *J Pharmacol Exp Ther* 256: 176–182.

Rocha, C. , Galvao, H. , and Barbosa, A. (2002) Role of transient silicon limitation in the development of cyanobacteria blooms in the Guadiana estuary, south western Siberia. *Mar Ecol Progr Ser* 228: 35–45.

Rogers, E. H. , Hunter, E. S. III., Moser, V. C. , Phillips, P. M. , Herkovits, J. , Munoz, L. , Hall, L. L. , and Chernoff, N. (2005) Potential developmental toxicity of anatoxin-a, a cyanobacterial toxin. *J Appl Toxicol* 25: 527–534.

Rohrback, T. , Dittmann, E. , Henning, M. , Borner, T. , and Kohl, J.-G. (1999) Role of microcystins in poisoning and food ingestion inhibition of *Daphnia galeata* caused by the cyanobacterium *Microcystis aeruginosa*. *Appl Environ Microbiol* 65: 737–739.

Rolland, A. , Bird, D. F. , and Giani, A. (2005) Seasonal changes in composition of the cyanobacterial community and the occurrence of hepatotoxic blooms in the eastern townships, Quebec, Canada. *J Plankton Res* 27: 683–694.

Rositano, J. , and Nicholson, B. C. (1994) Water Treatment Techniques for the Removal of Cyanobacterial Toxins from Water. Australian Centre for Water Treatment and Water Quality Research. Salisbury, South Australia.

Rositano, J. , Nicholson, B. , and Pieronne, P. (1998) Destruction of cyanobacterial toxins by ozone. *Ozone Sci Eng* 20: 223–238.

Rouhiainen, L. , Paulin, L. , Suomalainen, S. , Hyytiäinen, H. , Buikema, W. , Haselkorn, R. , and Sivonen, K. (2000) Genes encoding synthetases of cyclic depsipeptides, anabaenopeptilides, in *Anabaena* strain 90. *Mol Microbiol* 37: 156–167.

Rouhiainen, L. , Sivonen, K. , Buikema, W. J. , and Haselkorn, R. (1995) Characterization of toxin-producing cyanobacteria by using oligonucleotide probe containing a tandemly repeated heptamer. *J Bacteriol* 177: 6021–6026.

Rouhiainen, L. , Vakkilainen, T. , Siemer, B. L. , Buikema, W. , Haselkorn, R. , and Sivonen, K. (2004) Genes coding for hepatotoxins (microcystins) in the cyanobacterium *Anabaena* strain 90. *Appl Environ Microbiol* 70: 686–692.

Rounge, T. B. , Rohrback, T. , Tooming-Klunderud, A. , Kristensen, T. , and Jakobsen, K. S. (2007) Comparison of cyanopeptolin genes in *Planktothrix*, *Microcystis*, and *Anabaena* strains: Evidence for independent evolution within each genus. *Appl Environ Microbiol* 73: 7322–7330.

Rudi, K. , Larsen, F. , and Jakobsen, K. S. (1998) Detection of toxin producing cyanobacteria by use of paramagnetic beads for cell concentration and DNA purification. *Appl Environ Microbiol* 64: 34–37.

Rudolph-Boehner, S. , Mierke, D. F. , and Morder, L. (1994) Molecular structure of cyanobacterial tumor-promoting microcystins. *FEBS Lett* 349: 319–323.

Runnegar, M. T. , Berndt, N. , Kong, S. M. , Lee, E. Y. , and Zhang, L. (1995) In vivo and in vitro binding of microcystins to protein phosphatases 1 and 2A. *Biochem Biophys Res Commun* 216: 162–169.

Runnegar, M. T. C. , Falconer, I. R. , and Silver, J. (1981) Deformation of isolated rat hepatocytes by a peptide hepatotoxin from the blue-green alga *Microcystis aeruginosa*. *Naunyn-Schmiedeberg's Arch Pharmacol* 317: 268–272.

Runnegar, M. T. C. , Falconer, I. R. , Buckley, T. , and Jackson, A. R. (1986) Lethal potency and tissue distribution of ¹²⁵I-labelled toxic peptides from the blue-green alga *Microcystis aeruginosa*. *Toxicol* 24: 506–509.

Runnegar, M. T. C. , Falconer, I. R. , Jackson, A. R. B. , and McInnes, A. (1983) Toxin production by *Microcystis aeruginosa* cultures. *Toxicol* 3(Suppl): 377–377.

Runnegar, M. T. C. , Gerdes, R. G. , and Falconer, I. R. (1991) The uptake of cyanobacterial hepatotoxin microcystin by isolated rat hepatocytes. *Toxicol* 29: 43–51.

Runnegar, M. T. C. , Jackson, A. R. B. , and Falconer, I. R. (1988) Toxicity of the cyanobacterium *Nodularia spumigena mertens*. *Toxicol* 26: 143–151.

Runnegar, M. , Kong, S. , and Berndt, N. (1993) Protein phosphatase inhibition and in vivo hepatotoxicity of microcystins. *Am J Physiol* 265: G224–G230.

Runnegar, M. T. , Kong, S. M. , Zhong, Y. Z. , and Lu, S. C. (1995) Inhibition of reduced glutathione synthesis by cyanobacterial alkaloid cylindrospermopsin in cultured rat hepatocytes. *Biochem Pharmacol* 49: 219–225.

Runnegar, M. T. , Kong, S. M. , Zhong Y. Z. , Ge, J. L. , and Lu, S. C. (1994) The role of glutathione in the toxicity of a novel cyanobacterial alkaloid cylindrospermopsin in cultured rat hepatocytes. *Biochem Biophys Res Commun* 201: 235–241.

Runnegar, M. T. , Xie, C. , Snider, B. B. , Wallace, G. A. , Weinreb, S. M. , and Kuhlenskamp, J. (2002) In vitro hepatotoxicity of the cyanobacterial alkaloid cylindrospermopsin and related synthetic analogues. *Toxicol Sci* 67: 81–87.

Ryan, E. F. , Hamilton, D. P. , and Barnes, G. E. (2003) Recent occurrence of *Cylindrospermopsis raciborskii* in Waikato lakes of New Zealand. *New Zealand J Mar Freshwater Res* 37: 829–836.

Sabour, B. , Loudiki, M. , Oudra, B. , Vasconcelos, V. , Martins, R. , Oubraim, S. , and Fawzi, B. (2002) Toxicology of a *Microcystis* ichthyoblaste waterbloom from Lake Oued Mellah (Morocco). *Environ Toxicol* 17: 24–31.

Sahin, A. , Tencalla, F. G. , Dietrich, D. R. , Mez, K. , and Naegeli, H. (1995) Enzymatic analysis of liver samples from rainbow trout for diagnosis of blue-green algae-induced toxicosis. *Am J Vet Res* 56: 1110–1116.

Saito, K. , Konno, A. , Ishii, H. , Saito, H. , Nishida, F. , Abe, T. , and Chen, C. (2001) Nodularin-Har: A new nodularin from *Nodularia*. *J Nat Prod* 64: 139–141.

Saitou, T. , Sugiura, N. , Itayama, T. , Inamori, Y. , and Matsumura, M. (2003) Degradation characteristics of microcystins by isolated bacteria from lake Kasumigaura. *J Water Sci Res* 52: 13–18.

Saker, M. L. , and Griffiths, D. J. (2001) Occurrence of blooms of the cyanobacterium *Cylindrospermopsis raciborskii* (Woloszynska) Seenayya and Subba Raju in a north Queensland domestic water supply. *Mar Freshwater Res* 52: 907–915.

Saker, M. L. , and Neilan, B. A. (2001) Varied diazotrophies, morphologies, and toxicities of genetically similar isolates of *Cylindrospermopsis raciborskii* (Nostocales, Cyanophyceae) from Northern Australia. *Appl Environ Microbiol* 67: 1839–1845.

Saker, M. L. , Fastner, J. , Dittmann, E. , Christiansen, G. , and Vasconcelos, V. M. (2005) Variation between strains of the cyanobacterium *Microcystis aeruginosa* isolated from a Portuguese river. *J Appl Microbiol* 99: 749–757.

Saker, M. L. , Nogueira, I. C. G. , Vasconcelos, V. M. , Neilan, B. A. , Eaglesham, G. K. , and Pereira, P. (2003) Cyanobacterial toxins. In: Chorus, I. , and Bartram, J. (Eds.) *Toxic Cyanobacteria in Water: A Guide to Their Public Health Consequences, Monitoring and Management*. E and FN Spon, London, UK. pp. 41–111.

Saker, M. L. , Metcalf, J. S. , Codd, G. A. , and Vasconcelos, V. M. (2004) Accumulation and depurination of the cyanobacterial toxin cylindrospermopsin in freshwater mussel *Anodonta cygnea*. *Toxicol* 43: 185–194.

Saker, M. L. , Neilan, B. A. , and Griffiths, D. J. (1999a) Two morphological forms of *Cylindrospermopsis raciborskii* (cyanobacteria) isolated from Solomon dam, Palm Island, Queensland. *J Phycol* 35: 599.

Saker, M. L. , Thomas, A. D. , and Norton, J. H. (1999b) Cattle mortality attributed to the cyanobacterium *Cylindrospermopsis raciborskii* in an outback region of north Queensland. *Environ Toxicol* 41: 179–182.

Sano, T. , Takagi, H. , Morrison, L. F. , Metcalf, J. S. , Codd, G. A. , and Kaya, K. (2005) Leucine aminopeptidase M inhibitors, cyanostatin A and B, isolated from cyanobacterial water blooms in Scotland. *Phytochemistry* 66: 543–548.

Sawyer, P. , Gentile, J. , and Sasner, J. J. (1968) Demonstration of a toxin from *Aphanizomenon flos-aquae* (L) Ralfs. *Can J Microbiol* 14: 1199–1204.

Schatz, D. , Keren, Y. , Hadas, O. , Carmeli, S. , Sukenik, A. , and Kaplan, A. (2005) Ecological implications of the emergence of non-toxic subcultures from toxic *Microcystis* strains. *Environ Microbiol* 7: 798–805.

Schwimmer, D. , and Schwimmer, M. (1964). *Algae and medicine*. In: Jackson, D. F. (Ed.) *Algae and Man*. Plenum Press, New York, NY, USA. p. 434.

Seawright, A. A. , Nolan, C. C. , Shaw, G. R. , Chiswell, R. K. , Norris, R. L. , Moore, M. R. , and Smith, M. J. (1999) The oral toxicity for mice of the tropical cyanobacterium *Cylindrospermopsis raciborskii* (Woloszynska). *Environ Toxicol* 14: 135–142.

Sedmak, B. , and Kosi, G. (1997) Microcystins in Slovene freshwaters (central Europe)-first report. *Nat Toxins* 5: 64–73.

Seenayya, G. , and Subba Raju, S. N. (1972) On the ecology and systematics of the alga known as *Anabaenopsis raciborskii* (Wolosz.) Elenk. and a critical evaluation of the forms described under *Anabaenopsis*. In: Desikachary, T. V. (Ed.) *Taxonomy and Biology of Blue-green algae*. University of Madras, Madras pp. 52–57.

Seifert, M. , McGregor, G. , Eaglesham, G. , Wickramasinghe, W. , and Shaw, G. (2007) First evidence for the production of cylindrospermopsin and deoxycylindrospermopsin by the freshwater benthic cyanobacterium, *Lyngbya wollei* (Farlow ex Gomont) *Speziale und Dyck. Harmful Algae* 6: 73–80.

Selheim, F. , Herfindal, L. , Martin, R. , Vasconcelos, V. , and Døskeland, S. O. (2005) Neuroapoptogenic and blood platelet targeting toxins in benthic marine cyanobacteria from Portuguese coast. *Aquat Toxicol* 74: 294–306.

Shafik, H. , Voerres, L. , Sprober, P. , Presing, M. , and Kovacs, A. W. (2003) Some special morphological features of *Cylindrospermopsis raciborskii* in batch and continuous cultures. *Hydrobiologia* 506–509: 163–163.

Shalev-Alon, G. , Sukenik, A. , Livnah, O. , Schwarz, R. , and Kaplan, A. (2002) A novel gene encoding amidinotransferase in the cylindrospermopsin producing cyanobacterium *Aphanizomenon ovalisporum*. *FEMS Microbiol Lett* 209: 87–91.

Shaw, G. R. , Seawright, A. A. , Moore, M. R. , and Lam, P. K. (2000) Cylindrospermopsin, a cyanobacterial alkaloid: Evaluation of its toxicogenic activity. *Ther Drug Monit* 22: 89–92.

Shaw, G. R. , Sukenik, A. , Livne, A. , Chiswell, R. K. , Smith, M. J. , Seawright, A. A. , Norris, R. L. , Eaglesham, G. K. , and Moore, M. R. (1999) Blooms of the cylindrospermopsin containing cyanobacterium, *Aphanizomenon ovalisporum* (Forti) in newly constructed lakes, Queensland, Australia. *Environ Toxicol* 14: 167–177.

Shimizu, Y. , Norte, M. , Hori, A. , Genenah, A. , and Kobayashi, M. (1984) Biosynthesis of saxitoxin analogues: The unexpected pathway. *J Am Chem Soc* 106: 6433–6434.

Sielaff, H. , Dittman, E. , Tandeau De Marsac, N. , Bouchier, C. , von Doehren, H. , Borner, T. , and Schwecke, T. (2003) The *mcyF* gene of the microcystin biosynthetic gene cluster from *Microcystis aeruginosa* encodes an aspartate racemase. *Biochem J* 373: 909–916.

Sim, A. T. R. , and Mudge, L. M. (1993) Protein phosphatase activity in cyanobacteria-consequences for microcystin toxicity analysis. *Toxicon* 31: 1179–1186.

Singh, D. P. , Tyagi, M. B. , and Kumar, A. (1999) Cyanobacterial toxins. In: Fatma, N. (Ed.) *Cyanobacterial and Algal Metabolism and Environmental Biotechnology*. Narosa Publishing House, New Delhi, India. pp. 61–72.

Sipia, V. O. , Karlsson, K. M. , Meriluto, J. A. O. , and Kankaanpää, H. T. (2005) Eiders (*Somateria mollissima*) to obtain nodularin, a cyanobacterial hepatotoxin, in Baltic Sea food web. *Environ Toxicol Chem* 23: 1256–1260.

Siren, H. , Jussila, M. , Liu, H. W. , Peltoniemi, S. , Sivonen, K. , and Riekkola, M. L. (1999) Separation, purity testing and identification of cyanobacterial hepatotoxins with capillary electrophoresis and electron spray mass spectrometry. *J Chromatogr A* 839: 203–215.

Sivonen, K. (1990) Effect of light, temperature, nitrate, orthophosphate and bacteria on growth and hepatotoxin production by *Oscillatoria agardhii* strains. *Appl Environ Microbiol* 56: 2658–2666.

Sivonen, K. (1996) Cyanobacterial toxins and toxin production. *Phycologia* 35: 12–24.

Sivonen, K. , and Jones, J. (1999) Cyanobacterial toxins. In: Chorus, I. and Bartram, J. (Eds.). *Toxic Cyanobacteria in Water: A Guide to Public Health Significance, Consequences, Monitoring and Management*. E & FN SPON, London. pp. 41–111.

Sivonen, K. , Carmichael, W. W. , Namikoshi, M. , Rinehart, K. L. , Dahlem, M. , and Niemela, S. I. (1990a) Isolation and characterization of hepatotoxic microcystin homologues from the filamentous freshwater cyanobacterium *Nostoc* sp. strain 152. *Appl Environ Microbiol* 56: 2650–2657.

Sivonen, K. , Himberg, K. , Luukkainen, R. , Niemela, S. I. , Poon, G. K. , and Codd, G. A. (1989a) Preliminary characterization of neurotoxic cyanobacteria blooms and strains from Finland. *Toxic Assess* 4: 339–352.

Sivonen, K. , Kononen, K. , Carmichael, W. W. , Dahlem, A. M. , Rinehart, K. M. , Kiviranta, J. , and Niemela, S. I. (1989b) Occurrence of the hepatotoxic cyanobacterium *Nodularia spumigena* in the Baltic Sea and the structure of the toxin. *Appl Environ Microbiol* 55: 1990–1995.

Sivonen, K. , Namikoshi, M. , Evans, W. R. , Carmichael, W. W. , Sun, F. , Rouhaianen, L. , Luukkainen, R. , and Rinehart, K. L. (1992a) Isolation and characterization of a variety of microcystins from seven strains of the cyanobacterial genus *Anabaena*. *Appl Environ Microbiol* 58: 2495–2500.

Sivonen, K. , Namikoshi, M. , Evans, W. R. , Faerdig, M. , Carmichael, W. W. , and Rinehart, K. L. (1992b) Three new microcystins, cyclic heptapeptide hepatotoxins, from *Nostoc* sp. strain 152. *Chem Res Toxicol* 5: 464–469.

Sivonen, K. , Namikoshi, M. , Evans, W. R. , Gromov, B. V. , Carmichael, W. W. , and Rinehart, K. L. (1992c) Isolation and structures of five microcystins from a Russian *Microcystis aeruginosa* strain CALU 972. *Toxicon* 30: 1481–1485.

Sivonen, K. , Niemelä, S. I. , Niemi, R. M. , Lepistö, L. , Luoma, T. H. , and Räsänen, L. A. (1990b) Toxic cyanobacteria (blue-green algae) in Finnish fresh and coastal waters. *Hydrobiologia* 190: 267–275.

Sivonen, K. , Skulberg, O. M. , Namikoshi, M. , Evans, W. R. , Carmichael, W. W. , and Rinehart, K. L. (1992d) Two methyl ester derivatives of microcystins, cyclic heptapeptide hepatotoxins, isolated from *Anabaena flos-aquae* strain CYA 83/1. *Toxicon* 30: 1465–1471.

Skulberg, O. M. , Carmichael, W. W. , Anderson, R. A. , Matsunaga, S. , Moore, R. E. , Skulberg, R. (1992) Investigation of a neurotoxic *Oscillatoria* strain (cyanophyceae) and its toxin. Isolation and characterization of homoanatoxin-a. *Environ Toxicol Chem* 11: 321–329.

Smith, D. S. , and Watkinson, A. (1981) Anodic oxidation of phenol for wastewater treatment. *Can J Chem Eng* 59: 52–59.

Soliakov, L. , Gallagher, T. , and Wonnacott, S. (1995) Anatoxin-a evoked [3 H] dopamine release from rat striatal synaptosomes. *Neuropharmacol* 34: 1535–1541.

Solter, P. F. , Wollenberg, G. K. , Huang, X. , Chu, F. S. , and Runnegar, M. T. (1998) Prolonged sublethal exposure to the protein phosphatase inhibitor microcystin-LR results in multiple dose-dependent hepatotoxic effects. *Toxicol Sci* 44: 87–96.

Song, K. Y. , Lim, I. K. , Park, S. C. , Lee, S.O. , Park, H. S. , Choi, K. Y. , and Hyun, B. H. (1999) Effect of nodularin on the expression of glutathione S-transferase placental form and proliferating cell nuclear antigen in N-nitrosodiethylamine initiated hepatocarcinogenesis in the male Fischer 344 rat. *Carcinogenesis* 20: 1541–1548.

Song, W. , Teshiba, T. , Rein, K. , and O'Shea, K. E. (2005) Ultrasonically induced degradation and detoxification of microcystin-LR (cyanobacterial toxin). *Environ Sci Technol* 39: 6300–6305.

Spivak, C. E. , Witkop, B. , and Albuquerque, E. X. (1980) Anatoxin-a: A novel, potent agonist at the nicotinic receptor. *Mol Pharmacol* 18: 384–394.

Spoof, L. , Karlsson, K. , and Meriluto, J. (2001) High-performance liquid chromatographic separation of microcystins and nodularin, cyanobacterial peptide toxins, on C-18 and amide C-16 sorbents. *J Chromatogr* 909: 225–236.

Spoof, L. , Vesterkvist, P. , Lindhol, T. , and Meriluto, J. (2003) Screening for cyanobacterial hepatotoxins, microcystins and nodularins in environmental water samples by reversed-phase liquid chromatography-electron spray ionization mass spectrometry. *J Chromatogr* 1020: 105–119.

Spoof, L. , Berg, K. A. , Rapala, J. , Lahti, K. , Lepistö, L. , Metcalf, J. S. , Codd, G. A. , and Meriluoto, J. (2006) First observation of cylindrospermopsin in *Anabaena lapponica* isolated from the boreal environment (Finland). *Environ Toxicol* 21: 552–560.

Stachelhaus, T. , Schneider, A. , and Marahiel, M. A. (1995) Rational design of peptide antibiotics by targeted replacement of bacterial and fungal domains. *Science* 269: 69–72.

Steffensen DA , Nicholson BC , Burch MD , Drikas M , Baker PD (1999) Ecology and management of blue–green algae (cyanobacteria) in Australia. *Environ Toxicol Water Qual* 14: 183–195.

Stevens, D. K. , and Krieger, R. I. (189) Application of a sensitive, GC-ECD analysis for anatoxin-a. *Toxicon* 27: 79.

Stevens, D. K. , and Krieger, R. I. (1991) Stability studies on the cyanobacterial nicotinic alkaloid anatoxin-a. *Toxicon* 29: 167–169.

Stewart, I. , Schluter, P. J. , and Shaw, G. R. (2006) Cyanobacterial lipopolysaccharides and human health- a review. *Environ Health* 5: 7. doi:10.1186/1476-069X-5-7

Stoner, R. D. , Adams, W. H. , Slatkin, D. N. , and Siegelman, H. W. (1989) The effects of single L-amino acid substitutions on the lethal potencies of microcystins. *Toxicon* 27: 825–828.

Stotts, R. R. , Namikoshi, M. , Haschek, W. M. , Rinehart, K. L. , Carmichael, W. W. , Dahlem, A. M. , and Beasley, V. R. (1993) Structural modifications imparting reduced toxicity in microcystins from *Microcystis* spp. *Toxicon* 31: 783–789.

Stucken, K. , John, U. , Cembella, A. , Murillo, A. A. , Soto-Liebe, K. , Fuentes-Valdés, J. J. , Friedel, M. , Plominsky, A. M. , Vásquez, M. , and Glöckner, G. (2010) The smallest known genomes of multicellular toxic cyanobacteria: Comparison minimal gene sets for linked traits and the evolutionary implications. *PLoS ONE* 5: e9235. doi: 10.1371/journal.pone.0009235

Sudek, S. , Haygood, M. G. , Youssef, D. T. A. , and Schmidt, E. W. (2006) Structure of trichamide, a cyclic peptide from the bloom-forming cyanobacterium *Trichodesmium erythraeum* predicted from the genome sequence. *Appl Environ Microbiol* 72: 4382–4387.

Svreck, C. , and Smith, W. (2004) Cyanobacterial toxins and the current state of knowledge on water treatment options: A review. *J Environ Eng Sci* 3: 155–185.

Takenaka, S. , and Watanabe, M. F. (1997) Microcystin-LR degradation by *Pseudomonas aeruginosa* alkaline protease. *Chemosphere* 34: 749–757.

Takino, M. , Daishima, S. , and Yamaguchi, K. (1999) Analysis of anatoxin-a in freshwaters by automated on-line derivatization-liquid chromatography-electron spray mass spectrometry. *J Chromatogr* 862: 191–197.

Teixera, M. G. L. C. , Costa, M. C. N. , Carvalho, V. L. P. , Pereira, M. S. , and Hage, E. (1993) Gastroenteritis epidemic in the area of the Itaparica Dam, Bahia, Brazil. *Bull Pan Am Health Org* 27: 244–253.

Tencalla, F. , and Dietrich, D. (1997) Biochemical characterization of microcystin toxicity in rainbow trout (*Oncorhynchus mykiss*). *Toxicon* 34: 583–595.

Teneva, I. , Dzhambozov, B. , Koleva, L. , Mladenov, R. , and Schirmer, K. (2005b) Toxic potential of five freshwater *Phormidium* species (Cyanoprokaryota). *Toxicon* 45: 711–725.

Teneva, I. , Mladenov, R. , Popov, N. , and Dzhambozov, B. (2005a) Cytotoxicity and apoptotic effects of microcystin-LR and anatoxin-a in mouse lymphocytes. *Folia Biol (Praha)* 51: 62–67.

Teneva, L. , Visser, P. M. , Christiansen, G. , Dittman, E. , Snelder, E. O. , Wiedner, C. , Mur, L. R. , and Huisman, J. (2005) The microcystin composition of the cyanobacterium *Planktothrix agardhii* changes toward a more toxic variant with increasing light intensity. *Appl Environ Microbiol* 71: 5177–5181.

Terao, K. , Ohmori, S. , Igarashi, K. , Ohtani, I. , Watanabe, M. F. , Harada, K. I. , Ito, E. , and Watanabe, M. (1994) Electron microscopic studies on experimental poisoning in mice induced by cylindrospermopsin isolated from blue-green alga *Umezakia natans*. *Toxicon* 32: 833–843.

Thacker, R. W. , and Paul, V. J. (2004) Morphological, chemical, and genetic diversity of tropical marine cyanobacteria *Lyngbya* spp. and *Symploca* spp. (Oscillatoriales). *Appl Environ Microbiol* 70: 3305–3312.

Thomas, P. , Stephens, M. , Wilkie, G. , Amar, M. , Lunt, G. G. , Whiting, P. , Gallagher, T. , Pereira, E. , Alkondon, M. , and Albuquerque, E. X. (1993) (+) Anatoxin-a is a potent agonist at neural nicotinic acetylcholine receptors. *J Neurochem* 60: 2308–2311.

Theiss, W. C. , Carmichael, W. W. , Wyman, J. , and Bruner, R. (1988) Blood pressure and hepatocellular effects of the cyclic heptapeptide toxin produced by the freshwater cyanobacterium (blue-green alga) *Microcystis aeruginosa* strain PCC 7820. *Toxicon* 26: 603–613.

Tillett, D. , Dittmann, E. , Erhard, M. , von Döhren, H. , Börner, T. , and Neilan, B.A. (2000) Structural organization of microcystin biosynthesis in *Microcystis aeruginosa* PCC 7806: an integrated peptide-polyketide synthetase system. *Chem Biol* 7: 753–753.

Tillett, D. , Parker, D. L. , and Neilan, B. A. (2001) Detection of toxigenicity by a probe for the microcystin A gene (*mcyA*) of the cyanobacterial genus *Microcystis*: Comparison of toxicities with 16S rRNA and phycocyanin operon (phycocyanin intergenic spacer) phylogenies. *Appl Environ Microbiol* 67: 2810–2818.

Tisdale, E. S. (1931) Epidemic of intestinal disorders in Charleston W. Va., occurring simultaneously with unprecedented water supply conditions. *Am J Public Health* 21: 198–200.

Toivola, D. M. , Eriksson, J. E. , and Brautigan, D. L. (1994) Identification of protein phosphatase 2A as the primary target for microcystin-LR in rat liver homogenates. *FEBS Lett* 344: 175–180.

Tonk, L. , Visser, P. , Christiansen, G. , Dittmann, E. , Snelder, E. D. F. M. , Wiedner, C. , Mur, L. , and Huisman, J. (2005) The microcystin composition of the cyanobacterium *Planktothrix agardhii* changes toward a more toxic variant with increasing light intensity. *Appl Environ Microbiol* 71: 5177–5181.

Tooming-Klunderud, A. , Mikalsen, B. , Kristensen, T. , and Jakobsen, K.S. (2008) The mosaic structure of the *mcyABC* operon in *Microcystis*. *Microbiology* 154: 1886–1899.

Tooming-Klunderud, A. , Rohrlack, T. , Shalchian-Tabrizi, K. , Kristensen, T. , and Jakobsen, K. S. (2007) Structural analysis of a non-ribosomal halogenated cyclic peptide and its putative operon from *Microcystis*: Implications for evolution of cyanopeptolins. *Microbiology* 153: 1382–1393.

Törökne, A. K. (1997) Interlaboratory trial using Thamnotox kit for detecting cyanobacterial toxins. VIII Int Conf on Harmful Algae. Vigo, Spain. p. 114.

Törökne, A. K. , Laszlo, E. , Chorus, I. , Sivonen, K. , and Barbosa, F. A. R. (2000) Cyanobacterial toxins detected by Thamnotox kit (A double blind experiment). *Environ Toxicol* 15: 549–553.

Törökne, A. , Asztalos, M. , Bankine, M. , Bickel, H. , Borbely, G. , Carmeli, S. , Codd, G. A. , Fastner, J. , Huang, O. , Humpage, A. , Metcalf, J. S. , Rabai, E. , Sukenik, A. , Suranyi, G. , Vaas, G. , and Weiszfeiler, V. (2004) Interlaboratory comparison trial on cylindrospermopsin measurement. *Anal Biochem* 332: 280–284.

Tsuji, K. , Naito, S. , Kondo, F. , Ishikawa, N. , Watanabe, M. F. , Suzuki, M. , and Harada, K.-I. (1994a) Stability of microcystins from cyanobacteria: Effect of light on decomposition and isomerization. *Environ Sci Technol* 28: 173–177.

Tsuji, K. , Naito, S. , Kondo, F. , Watanabe, M. F. , Suzuki, S. , Nakazawa, H. , Suzuli, M. , Shimada, T. , and Harada, K. (1994b) A clean-up method for analysis of trace amounts of microcystins in lake water. *Toxicon* 32: 1251–1259.

Tsuji, K. , Setsuda, S. , Watanuki, T. , Kondo, F. , Nakazawa, H. , Suzuki, M. , and Harada, K.-I. (1996) Microcystin levels during 1992–95 for Lakes Sagami and Tsukui-Japan. *Nat Toxins* 4: 189–194.

Tsuji, K. , Watanuki, T. , Kondo, F. , Watanabe, M. F. , Suzuki, S. , Nakazawa, H. , Suzuki, M. , Uchida, H. , and Harada, K.-I. (1995) Stability of microcystins from cyanobacteria-II. Effect of UV light on the decomposition and isomerization. *Toxicon* 33: 1619–1631.

Tsutsumi, T. , Nagata, S. , Hasegawa, A. , and Ueno, Y. (2000) Immunoaffinity column as clean-up tool for determination of trace amounts of microcystins in tap water. *Food Chem Technol* 38: 593–597.

Turner, P. C. , Gammie, A. J. , Hollinrake, K. , and Codd, G. A. (1990) Pneumonia associated with contact with cyanobacteria. *Br Med J* 300: 1440–1441.

Twist, H. , and Codd, G. A. (1997) Degradation of the cyanobacterial hepatotoxin, nodularin, under light and dark conditions. *FEMS Microbiol Lett* 151: 83–88.

Utkilen, H. , and Gjølme, N. (1992) Toxin production by *Microcystis aeruginosa* as a function of light in continuous cultures and its ecological significance. *Appl Environ Microbiol* 58: 1321–1325.

Utkilen, H. , and Gjølme, N. (1995) Iron-stimulated toxin production in *Microcystis aeruginosa*. *Appl Environ Microbiol* 61: 797–800.

Utkilen, H. , Skulberg, O. M. , Skulberg, R. , Gjølme, N. , and Underdal, B. (2001) Toxic cyanobacterial blooms of inland waters in Southern Norway 1878–1998. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes and Consequences*. Springer, Berlin, Germany. pp. 46–49.

Ueno, Y. , Nagata, S. , Tsutsumi, T. , Hasegawa, A. , Watanabe, M. F. , Park, H. D. , Chen, G. , and Yu, S. Z. (1996) Detection of microcystin, a blue-green algal hepatotoxin, in drinking water sampled in Haimen and Fusui, endemic areas of primary liver cancer in China, by highly sensitive immunoassay. *Carcinogenesis* 17: 1317–1321.

Usleber, E. , Scheider, E. , Terplan, G. , and Laycock, M. V. (1995) Two formats of enzyme immunoassay for the detection of saxitoxin and other paralytic shellfish poisoning toxins. *Food Add Contam* 12: 405–413.

Vaas, G. , Gasper, A. , Pager, C. , Suranyi, G. , Mathe, C. , Hamvas, M. M. , and Borbely, G. (2004) Analysis of cyanobacterial toxins (anatoxin-a, cylindrospermopsin, microcystin-LR) by capillary electrophoresis. *Electrophoresis* 25: 108–115.

Vaitomaa, J. , Rantala, A. , Halinen, K. , Rouhiainen, L. , Tallberg, P. , Møkelke, L. , and Sivonen, K. (2003) Quantitative real-time PCR for determination of microcystin synthetase E copy numbers for *Microcystis* and *Anabaena* in Lakes. *Appl Environ Microbiol* 69: 7289–7297.

Van der Westhuizen, A. J. , and Eloff, J. N. (1985) Effect of temperature and light on the toxicity and growth of the blue-green alga *Microcystis aeruginosa* (UV-006). *Planta* 163: 55–59.

Van der Westhuizen, A. J. , Eloff, J. N. , and Krueger, G. H. J. (1986) Effect of temperature and light (fluence rate) on the composition of the toxin of the cyanobacterium *Microcystis aeruginosa* (UV-006). *Arch Hydrobiol* 108: 145–154.

Van Buynder, P. G. , Oughtred, T. , Kirby, B. , Phillips, S. , Eaglesham, G. , Thomas, K. , and Burch, M. (2001) Nodularin uptake by seafood during a cyanobacterial bloom. *Environ Toxicol* 16: 468–471.

Van Halderen, A. , Harding, W.R. , Wessels, J. C. , Schneider, D. J. , Heine, E. W. , Van der Merwe, J. , and Fourie, J. M. (1995) Cyanobacterial (blue-green algae) poisoning of livestock in the western Cape province of South Africa. *J S Afr Vet Assoc* 66: 260–264.

Vasconcelos, V. (1993) Toxicity of cyanobacteria in lakes of North and Central Portugal. Ecological implications. *Verh Internat Verein Limnol* 25: 694–697.

Vasconcelos, V. (1994) Toxic cyanobacteria (blue-green algae) in Portuguese freshwaters. *Arch Hydrobiol* 130: 439–451.

Vasconcelos, V. (1999) Cyanobacterial toxins in Portugal: Effects on aquatic animals and risk for human health. *Braz J Med Biol Res* 32: 249–254.

Vasconcelos, V. , and Pereira, (2001) Cyanobacteria diversity and toxicity in a wastewater treatment plant (Portugal). *Water Res* 35: 1354–1357.

Vasconcelos, V. , Oliveira, S. , and Teles, F. O. (2001) Impact of a toxic and a non-toxic strain of *Microcystis aeruginosa* on the crayfish *Procambarus clarkii*. *Toxicon* 39: 1461–1470.

Vasconcelos, V. , Sivonen, K. , Evans, W. R. , Carmichael, W. W. , and Namikoshi, M. (1996) Hepatotoxic microcystin diversity in cyanobacterial blooms collected in Portuguese waters. *Water Res* 30: 2377–2384.

Vézic, C. , Brient, L. , Sivonen, K. , Betru, G. , Lefeuvre, J.-C. , Salkinoja-Salonen, M. (1998) Variation of microcystin content of cyanobacterial blooms and isolated strains in Lake Grand-Lieu (France). *Microb Ecol* 35: 126–135.

Vézic, C. , Rapala, J. , Vaitomaa, J. , Seitsonen, J. , and Sivonen, K. (2002) Effect of nitrogen and phosphorus on growth of toxic and non-toxic strains of *Microcystis* strains and on intracellular microcystin concentrations. *Microb Ecol* 43: 443–454.

Via-Ordorika, L. , Fastner, J. , Kurmayer, R. , Hisbergues, M. , Dittmann, E. , Komarek, J. , Erhard, M. , and Chorus, I. (2004) Distribution of microcystin-producing and non-microcystin-producing *Microcystis* sp. in European freshwater bodies: Detection of microcystins and microcystin genes in individual colonies. *System Appl Microbiol* 27: 592–602.

- Vlyssides, A. G. , and Israilides, C. J. (1998) Electrochemical oxidation of a textile dye and finishing wastewater using a Pt/Ti electrode. *J Environ Sci Health* 33: 847–862.
- Volterra, L. , Bruno, M. , Gucci, P. M. B. , and Pierdominici, E. (1992) Fast method for detecting toxic cyanophyte blooms. *Environ Toxicol Water Qual* 7: 215–222.
- von Elert, E. , Oberer, L. , Merkel, P. , Huhn, T. , and Blom, J. F. (2005) Cyanopeptolin 954, a chlorine-containing chymotrypsin inhibitor of *Microcystis aeruginosa* NIVA Cya 43. *J Nat Prod* 68: 1324–1327.
- Ward, C. J. , Beattie, K. A. , Lee, E. Y. C. , and Codd, G. A. (1997) Colorimetric protein phosphatase inhibition assay of laboratory strains and natural blooms of cyanobacteria: Comparison of high-performance liquid chromatographic analysis for microcystins. *FEMS Microbiol Lett* 153: 465–473.
- Watanabe, M. (1995) Studies on planktonic blue-green algae. 5. A new species of *Cylindrospermopsis* (Nostocaceae) from Japan. *Bull Natl Sci Mus* 21: 45–48.
- Watanabe, M. F. , and Oishi, S. (1985) Effects of environmental factors on toxicity of a cyanobacterium (*Microcystis aeruginosa*) under culture conditions. *Appl Environ Microbiol* 49: 1342–1344.
- Watanabe, M. F. , Oishi, S. , Harada, K. , Matsuura, K. , Kawai, H. , and Suzuki, M. (1988) Toxins contained in *Microcystis* species of cyanobacteria (blue-green algae). *Toxicon* 26: 1017–1025.
- Watanabe, M. F. , Oishi, S. , Watanabe, Y. , and Watanabe, M. (1986) Strong possibility of lethal toxicity in the blue-green alga *Microcystis viridis* Lemm. *J Phycol* 22: 552–556.
- Watanabe, M. F. , Watanabe, M. , Kato, T. , Harada, K.-I. , and Suzuki, M. (1989) Heptapeptide toxin production during the batch culture of two *Microcystis* species (cyanobacteria). *J Appl Phycol* 1: 161–165.
- Watts, J. S. , Reilly, J. , Dacosta, F. , and Krop, S. (1966) Acute toxicity of paralytic shellfish poison in rats of different ages. *Toxicol Appl Pharmacol* 8: 286–294.
- Weckesser, J. , Martin, C. , and Jakobi, C. (1996) Cyanopeptolins, depsipeptides from cyanobacteria. *Syst Appl Microbiol* 19: 133–138.
- Welker, M. , and Steinberg, C. H. (1999) Indirect photolysis of cyanotoxins: One possible mechanism for their low persistence. *Water Res* 33: 1159–1164.
- Welker, M. , and von Dohren, H. (2006) Cyanobacterial peptides-Nature's own combinatorial biosynthesis. *FEMS Microbiol Rev* 30: 530–563.
- Welker, M. , Christiansen, G. , and von Dohren, H. (2004a) Diversity of coexisting Planktothrix (Cyanobacteria) chemotypes deduced by mass spectral analysis of microcystins and other oligopeptides. *Arch Microbiol* 182: 288–298.
- Welker, M. , Brunke, M. , Preussel, K. , Lippert, I. , and von Dohren, H. (2004b) Diversity and distribution of *Microcystis* (Cyanobacteria) oligopeptide chemotypes from natural communities studied by single colony mass spectrometry. *Microbiology* 150: 1785–1796.
- Welker, M. , von Dohren, H. , Tauscher, H. , Steinberg, C. E. W. , and Erhard, M. (2003) Toxic *Microcystis* in shallow lake Muggelsee (Germany)- dynamics, distribution, diversity. *Arch Hydrobiol* 157: 227–248.
- Weller, M. G. , Zeck, A. , Eikenberg, A. , Nagata, S. , Ueno, Y. , and Niessner, R. (2001) Development of a direct competitive microcystin immunoassay of broad specificity. *Anal Sci* 17: 1445–1448.
- Welsh, J. , and McClelland, M. (1990) Fingerprinting genomes using PCR with arbitrary primers. *Nucleic Acids Res* 18: 7213–7218.
- Wera, S. , and Hemmings, B. A. (1995) Serine/threonine protein phosphatases. *Biochem J* 311: 17–29.
- White, S. H. , Duivenvoorden, L. J. , and Fabbro, L. D. (2005) A decision making framework for ecological impacts associated with the accumulation of cyanotoxins (cylindrospermopsin and microcystin). *Lakes Reservoirs: Research Management* 10: 25–37. doi: 10.1111/j.1440-1770.2005.00258.x.
- WHO (1998) Guidelines for Drinking Water Quality. 2nd edn. Addendum to volume 2. Health Criteria and Other Supporting Information. World Health Organization, Geneva, Switzerland.
- WHO (2003) Algae and cyanobacteria in freshwater. In: Guidelines for Safe Recreational Water Environments. Volume 1: Coastal and freshwaters. World Health Organization, Geneva, Switzerland. pp. 136–158.
- WHO (2004) Guidelines for Drinking Water Quality. 3rd Edition. World Health Organization, Geneva, Switzerland.
- Wiberg, G. S. , and Stephenson, N. R. (1960) Toxicological studies on paralytic shellfish poison. *Toxicol Appl Pharmacol* 2: 607–615.
- Wickstrom, M. L. , Khan, S. A. , Haschek, W. M. , Wyman, J. F. , Eriksson, J. E. , Schaeffer, D. J. , and Beasley, V. R. (1995) Alterations in microtubules, intermediate filaments, and microfilaments induced by microcystin-LR in cultured cells. *Toxicol Pathol* 23: 326–337.
- Wiedner, C. , Chorus, I. , and Fastner, J. (2001) The water bodies surveyed for cyanotoxins in Germany. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes, Consequences*. Springer, Berlin, Germany. pp. 6–21.
- Wiedner, C. , Visser, P. M. , Fastner, J. , Metcalf, J. S. , Codd, G. A. , and Mur, L. R. (2003) Effects of light on the microcystin content of *Microcystis* strain PCC 7806. *Appl Environ Microbiol* 69: 1475–1481.
- Wiegand, C. , and Pflugmacher, S. (2001) Uptake of microcystin-LR in aquatic organisms. In: Chorus, I. (Ed.) *Cyanotoxins-Occurrence, Causes, Consequences*. Springer, Berlin, Germany. pp. 240–248.
- Wigmans, T. (1989) Industrial aspects of production and use of activated carbon. *Carbon* 27: 13–22.
- Willen, E. , Ahlgren, G. , and Soederhielm, A.-C. (2000) Toxic cyanophytes in three Swedesh Lakes. *Verh Internat Verein Limnol* 27: 560–564.
- Willame, R. , and Hoffmann, L. (1999) Bloom-forming blue-green algae in Belgium and Luxembourg. *Arch Hydrobiol (Suppl) Algal Stud* 94: 365–376.
- Willame, R. , Jurczak, T. , Iffly, J.-F. , Kull, T. , and Meriluto, J. (2005) Distribution of hepatotoxic cyanobacterial blooms in Belgium and Luxembourg. *Hydrobiologia* 551: 99–117.
- Williams, D. E. , Dawe, S. C. , Kent, M. L. , Anderson, R. J. , Craig, M. , and Holmes, C. F. B. (1997) Bioaccumulation and clearance of microcystins from salt water mussels, *Mytilus edulis*, and in vivo evidence for covalently bound microcystins in mussel tissues. *Toxicon* 35: 1617–1625.
- Williams, J. G. K. , Kubelik, A. R. , Livak, K. J. , Rafalski, J. A. , and Tingey, S. V. (1990) DNA polymorphisms amplified by arbitrary primers are useful as genetic markers. *Nucleic Acids Res* 18: 6531–6535.
- Williams, P. G. , Moore, R. E. , and Paul, V. J. (2003) Isolation and structure determination of lyngbyastatin 3, a lyngbyastatin 1 homologue from the marine cyanobacterium *Lyngbya majuscula*. Determination of the configuration of the 4-amino-2, 2-dimethyl-3-oxopentanoic acid unit in majusculamide C, dolastatin 12, lyngbyastatin 1, and lyngbyastatin 3 from cyanobacteria. *J Nat Prod* 66: 1356–1363.
- Wilson, A. E. , Sarnelle, O. , Neilan, B. A. , Salmon, T. P. , Gehringer, M. M. , and Hay, M. E. (2005) Genetic variation of the bloom-forming cyanobacterium *Microcystis aeruginosa* within and among lakes: Implications for harmful algal blooms. *Appl Environ Microbiol* 71:

- Wilson, K. M. , Schembri, M. A. , Baker, P. D. , and Saint, C. P. (2000) Molecular characterization of the toxic cyanobacterium *Cylindrospermopsis raciborskii* and design of a species-specific PCR. *Appl Environ Microbiol* 66: 332–338.
- Wirsing, B. , Flury, T. , Wiedner, C. , Neumann, U. , and Weckesser, J. (1999) Estimation of the microcystin content in cyanobacterial field samples from German lakes using the colorimetric protein-phosphatase inhibition assay and RP-HPLC. *Environ Toxicol* 14: 23–29.
- Wirsing, B. , Hoffmann, L. , Heinze, R. , Klein, D. , Daloze, D. , Braekman, J. C. , and Weckesser, J. (1998) First report on the identification of microcystin in a water bloom collected in Belgium. *Sys Appl Microbiol* 21: 23–27.
- Wonnacott, S. , Jackman, S. , Swanson, K. L. , Rapoport, H. , and Albuquerque, E. X. (1991) Nicotinic pharmacology of anatoxin analogs. II. Side chain structure-activity relationships at neuronal nicotinic ligand binding sites. *J Pharmacol Exptl Therapeutics* 259: 387–391.
- Wood, S. A. , Briggs, L. R. , Sporsen, J. , Ruck, J.G. , Wear, R. G. , Holland, P. T. , and Bloxham, M. (2006) Changes in concentrations of microcystins in rainbow trout, freshwater mussels and cyanobacteria in lakes Rotoiti and Rotoehu. *Environ Toxicol* 21: 205–222.
- Wood, S. A. , Mountfort, D. , Selwood, A. I. , Holland, P. T. , Puddick, J. , and Cary, S. C. (2008) Widespread distribution and identification of eight novel microcystins in Antarctic cyanobacterial mats. *Appl Environ Microbiol* 74: 7243–7251.
- Wu, J.-Y. , Xu, Q.-J. , Gao, G. , and Shen, J.-H. (2006) Evaluating genotoxicity associated with microcystin-LR and its risk to source water safety in Meiliang Bay, Taihu Lake. *Environ Toxicol* 21: 250–255.
- Wu, M. , Okino, T. , Nogle, L. M. , Marquez, B. L. , Williamson, R. T. , Sitachitta, N. , Berman, F. W. , Murray, T. F. , McGough, K. , Jacobs, R. , Colson, K. , Asano, T. , Yokokawa, F. , Shiori, T. , and Gerwick, W. H. (2000) Structure, synthesis and biological properties of kalkitoxin, a novel neurotoxin from the marine cyanobacterium *Lyngbya majuscula*. *J Am Chem Soc* 122: 12041–12042.
- Wyllie, A. H. , Kerr, J. F. , and Currie, A. R. (1980) Cell death: The significance of apoptosis. *Int Rev Cytol* 68: 251–306.
- Xagorarakis, I. , Harrington, G. W. , Zulliger, K. , Zeier, B. , Krick, W. , Karner, D. A. , Standridge, J. H. , and Westrick, J. (2006) Inactivation kinetics of the cyanobacterial toxin microcystin-LR by free chlorine. *J Environ Eng* 132: 818–823.
- Xie, C. , Runnegar, M. T. C. , and Snider, B. B. (2000) Total synthesis of ($\pm$) cylindrospermopsin. *J Am Chem Soc* 122: 5017–5024.
- Xu, L. H. , Lam, P. K. S. , Chen, J. P. , Xu, J. M. , Wong, B. S. F. , Zhang, Y. Y. , Wu, R. S. S. , and Harada, K.-I. (2000) Use of protein phosphatase inhibition assay to detect microcystins in Donghu Lake and a fish pond in China. *Chemosphere* 41: 53–58.
- Xu, L. H. , Lam, P. K. , Chen, J. P. , Xu, J. M. , Wong, B. S. , Zhang, Y. Y. , Wu, R. S. , and Harada, K.-I. (2002) Use of protein phosphatase inhibition assay to detect microcystins in Donghu Lake and a fish pond in China. *Chemosphere* 41: 53–58.
- Yamasaki, H. (1988) Multistage carcinogenesis: Implications for risk estimation. *Cancer Metastasis Rev* 7: 5–18.
- Yilmaz, M. , and Philips, E. J. (2011) Diversity and selection acting on cylindrospermopsin cryB gene adenylation domain sequences in Florida. *Appl Environ Microbiol* 77: 2502–2507. doi:10.1128/AEM.02252-10.
- Yokokawa, F. , Fujiwara, H. , and Shioiri, T. (1999) Total synthesis and revision of absolute configuration of antillatoxin, an ichthyotoxic cyclic lipopeptide of marine origin. *Tetrahedron Lett* 40: 1915–1916.
- Yokokawa, F. , Fujiwara, H. , and Shioiri, T. (2000a) Total synthesis and revision of absolute stereochemistry of antillatoxin, an ichthyotoxic cyclic lipopeptide from marine cyanobacterium *Lyngbya majuscula*. *Tetrahedron* 56: 1759–1775.
- Yokokawa, F. , Shioiri, T. , and Gerwick, W. H. (2000b) Structure, synthesis and biological properties of kalkitoxin, a novel neurotoxin from the marine cyanobacterium *Lyngbya majuscula*. *J Am Chem Soc* 122: 12041–12042.
- Yoshida, T. , Makita, Y. , Tsutsumi, T. , Nagata, S. , Tashiro, F. , Yoshida, F. , Sekijima, M. , Tamura, S.-I. , Harada, T. , Maita, K. , and Ueno, Y. (1998) Immunohistochemical localization of microcystin-LR in the liver of mice: A study on the pathogenesis of microcystin-LR-induced hepatotoxicity. *Toxicol Pathol* 26: 411–418.
- Yoshida, T. , Yuki, Y. , Lei, S. , Chinen, H. , Yoshida, M. , Kondo, R. , and Hiroishi, S. (2003) Quantitative detection of toxic strains of the cyanobacterial genus *Microcystis* by competitive PCR. *Microbes Environ* 18: 16–23.
- Yoshizawa, S. , Matsushima, R. , Watanabe, M. F. , Harada, K.-I. , Ichihara, A. , Carimachael, W. W. , Fujiki, H. (1990) Inhibition of protein phosphatases by microcystins and nodularin associated with hepatotoxicity. *J Cancer Res Clin Oncol* 116: 609–614.
- Young, F. M. , Thomson, C. , Metcalf, J. S. , Lucocq, J. M. , and Codd, G. A. (2005) Immunogold localisation of microcystins in cryosectioned cells of *Microcystis*. *J Struct Biol* 151: 208–214.
- Yu, S.-Z. (1989) Drinking water and primary liver cancer. In: Tang, Z.-Y. , Wu, M.-C. , and Xia, S.-S. (Eds.) *Primary Liver Cancer*. Springer-Verlag, New York, NY, USA. pp. 30–37.
- Yuan, M. , Namikoshi, M. , Otsuki, A. , and Sivonen, K. (1998) Effect of amino acid-side chain on fragmentation of cyclic peptide ions: Differences of electron spray ionization-induced decomposition mass spectra of toxic heptapeptide microcystins containing ADMAdda instead of Adda. *Eur Mass Spectrom* 4: 287–298.
- Yuan, M. , Namikoshi, M. , Otsuki, A. , Rinehart, K. L. , Sivonen, K. , and Watanabe, M. F. (1999a) Low-energy collisionally activated decomposition and structural characterization of cyclic heptapeptide microcystins by electron spray ionization mass spectrometry. *J Mass Spectrom* 34: 33–43.
- Yuan, M. , Namikoshi, M. , Otsuki, A. , Watanabe, M. F. , and Rinehart, K. L. (1999b) Electrospray ionization mass spectrometric analysis of microcystins, cyclic heptapeptide hepatotoxins: Modulation of charge states and $[M+H]^+$ to $[M+Na]^+$ ratio. *J Am Soc Mass Spectrom* 10: 1138–1151.
- Yunes, J. S. , Salomon, P. S. , Matthiensen, A. , Beattie, K. A. , Raggett, S. L. , and Codd, G. A. (1996) Blooms of cyanobacteria in the Patos Lagoon estuary, in Southern Brazil. *J Aquat Ecosys Health* 5: 223–229.
- Zegura, B. , Sedmak, B. , and Filipic, M. (2003) Microcystin-LR induces oxidative DNA damage in human hepatoma cell line HepG2. *Toxicol* 41: 41–48.
- Zhan, L. , Sakamoto, H. , Sakuraba, M. , Wude, S. , Zhang, L. S. , Suzuki, T. , Hayashi, M. , and Honma, M. (2004) Genotoxicity of microcystin-LR in human lymphoblastoid TK6 cells. *Mutat Res* 557: 1–6.
- Zhang, L. , Ping, X. , and Yang, Z. (2004) Determination of microcystin-LR in surface water using high-performance liquid chromatography/tandem electrospray ionization mass detector. *Talanta* 62: 193–200.
- Zhang, Z. , Zhao, S. , Long, F. , Zhang, L. , Bai, G. , Shima, H. , Nagao, M. , Lee, E. Y. C. (1994) A mutant of protein phosphatase-1 that exhibits altered toxin sensitivity. *J Biol Chem* 269: 16997–17000.
- Zhou, L. , Yu, H. , and Chen, K. (2002) Relationship between microcystin in drinking water and colorectal cancer. *Biomed Environ Sci* 15: 166–171.
- Ziemert, N. , Ishida, K. , Quillardet, P. , Bouchier, C. , Hertweck, C. , Tndeau de Marsac, N. , and Dittmann, E. (2008) Microcyclamide biosynthesis in two strains of *Microcystis aeruginosa*: From structure to genes and vice versa. *Appl Environ Microbiol* 74: 1791–1797.

Znachor, P. , Jurczak, T. , Komarkova, J. , Jezberova, J. , Mankiewicz, J. , Kastovska, K. , and Zapomelova, E. (2006) Summer changes in cyanobacterial bloom composition and microcystin concentration in eutrophic Czech reservoirs. *Environ Toxicol* 21: 236–243.

Zurawell, R. W. , Kotak, B. G. , and Prepas, E. E. (1999) Influence of lake trophic status on the occurrence of microcystin-LR in the tissue of pulmonate snails. *Freshwater Biol* 42: 707–718.

Zweigenbaum, J. A. , Henion, J. D. , Beattie, K. A. , Codd, G. A. , and Poon, G. K. (2000) Direct analysis of microcystins by microbore liquid chromatography electrospray ionization ion-trap mass spectrometry. *J Pharm Biomed Anal* 23: 723–733.

Stress Responses

Akai, M. , Oai, K. , Kusano, M. , Sato, M. , Redestig, H. , Toyooka, K. , Morishita, M. , Miyake, H. , Hazama, A. , Checchetto, K. , Szabo, I. , Matsuo, K. , Saito, K. , Yasui, M. , Ishiura, M. , and Uozumi, N. (2011) Plasma membrane aquaporin AqpZ is essential for glucose metabolism during photomixotrophic growth of *Synechocystis* sp. PCC 6803. *J Biol Chem* 286: 25224–25235. doi:10.1074/jbc.M111.236385

Akiyama, Y. , and Ito, K. (2000) Roles of multimerization and membrane association in the proteolytic functions of FtsH (HflB). *Embo J* 19:3888–3895.

Akiyama, Y. , Yoshihisa, T. , and Ito, K. (1995) FtsH, a membrane-bound ATPase, forms a complex in the cytoplasmic membrane of *Escherichia coli*. *J Biol Chem* 270: 23485–23490.

Alam, J. , Curtis, S. , Gleason, F. K. , Gerami-Nejad, M. , and Fuchs, J. A. (1989) Isolation, sequence, and expression in *Escherichia coli* of an unusual thioredoxin gene from the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 171:162–171.

Alfonso, M. , Perewoska, I. , and Kirilovsky D. (2000) Redox control of psbA gene expression in the cyanobacterium *Synechocystis* PCC 6803. Involvement of the cytochrome b6/f complex. *Plant Physiol* 122: 505–515.

Alfonso, M. , Perewoska, I. , and Kirilovsky, D. (2001) Redox control of ntcA gene expression in *Synechocystis* sp. PCC 6803. Nitrogen availability and electron transport regulate the levels of the NtcA protein. *Plant Physiol* 125: 969–981.

Allakhverdiev, S. I. , and Murata, N. (2008) Salt stress inhibits photosystem II and I in cyanobacteria. *Photosynth Res* 98: 529–539. doi:10.1007/s1120-008-933-x

Allakhverdiev, S. I. , Kinoshita, M. , Inaba, M. , Suzuki, I. , and Murata, N. (2001) Unsaturated fatty acids in membrane lipids protect the photosynthetic machinery against salt induced damage in *Synechococcus*. *Plant Physiol* 125:1842–1853.

Allakhverdiev, S. I. , Nishiyama, Y. , Suzuki, I. , Tasaka, Y. , and Murata, N. (1999) Genetic engineering of the unsaturation of fatty acids in membrane lipids alters the tolerance of *Synechocystis* to salt stress. *Proc Natl Acad Sci USA* 96: 5862–5867.

Allakhverdiev, S. I. , Nishiyama, Y. , Miyairi, S. , Yamamoto, H. , Inagaki, N. , Kanesaki, Y. , and Murata, N. (2002) Salt stress inhibits the repair of photodamaged photosystem II by suppressing the transcription and translation of psbA genes in *Synechocystis*. *Plant Physiol* 130:1443–1453.

Allakhverdiev, S. I. , Sakamoto, A. , Nishiyama, Y. , Inaba, M. , and Murata, N. (2000a) Ionic and osmotic effects of NaCl induced inactivation of photosystems I and II in *Synechococcus* sp. *Plant Physiol* 123:1047–1056.

Allakhverdiev, S. L. , Sakamoto, A. , Nishiyama, Y. , and Murata, N. (2000b) Inactivation of photosystems I and II in response to osmotic stress in *Synechococcus*. Contribution of water channels. *Plant Physiol* 122:1201–1208.

Allen, M. B. , and Arnon, D. I. (1955) Studies on nitrogen-fixing blue-green algae. I. Growth and nitrogen fixation by *Anabaena cylindrica* Lemm. *Plant Physiol* 30:366–372.

Allen, S. P. , Polazzini, J. O. , Giersem, J. K. , and Easton, A. M. (1992) Two novel heat shock genes encoding proteins produced in response to heterologous protein expression in *Escherichia coli*. *J Bacteriol* 174: 6938–6947.

Alpert, P. (2005) The limits and frontiers of desiccation tolerant life. *Integr Comp Biol* 45: 685–695.

Alpert, P. (2006) Constraints of tolerance: Why are desiccation tolerant organisms so small or rare? *J Exp Biol* 209: 1575–1584.

Amarpalli, R. , Tripathy, P. , and Adhikary, S. P. (1997) Epilithic blue-green algae (cyanobacteria) from temples of India and Nepal. Presence of UV sunscreen pigments. *Arch Hydrobiol Algol Stud* 86:147–161.

Anagnostidis, K. , and Pantazidou, A. (1988) Endolithic cyanophytes from the saline thermal springs of Aedipsos, Halls (Greece). *Arch Hydrobiol Algol Stud* 50–53 (Suppl 80): 555–559.

Anbudurai, P. R. , Mor, T. S. , Ohad, I. , Shestakov, S. V. , and Pakrasi, H. B. (1994) The ctpA gene encodes the C-terminal processing protease for the D1 protein of photosystem II reaction center complex. *Proc Natl Acad Sci USA* 91: 8082–8086.

Andersen, P. A. , Kaasen, I. , Styrud, O. B. , Boulnois, G. , and Strom, A.R. (1988) Molecular cloning, physical mapping and expression of the bet genes governing the osmoregulatory choline-glycine betaine pathway of *Escherichia coli*. *J Gen Microbiol* 134:1737–1746.

Anderson, A. W. , Nordan, H. C. , Cain, R. R. , Parrish, G. , and Duggan, D. (1956) Studies on a radio-resistant micrococcus. I. Isolation, morphology cultural characteristics, and resistance to gamma radiation. *Food Technol* 10: 575–578.

Andersson, F. I. , Blankytný R. , Kirsten, J. , Turgay K. , Bukau, B. , Mogk, A. , and Clarke, A. K. (2006) Cyanobacterial ClpC/Hsp100 protein displays intrinsic chaperone activity *J Biol Chem* 281: 5468–5475.

Andersson, F. I. , Tryggvesson, A. , Sharon, M. , Diemand, A. V. , Classen, M. , Best, C. , Schmidt, R. , Schelin, J. , Stanne, T. M. , Bujau, B. , Robinson, C. V. , Witt, S. , Mogk, A. , and Clarke, A. K. (2009) Structure and function of a novel type of ATP-dependent Clp protease. *J Biol Chem* 284:13519–13532.

Angeloni, S.V. , and Potts, M. (1986) Polysome turnover in immobilized cells of *Nostoc commune* (cyanobacteria) exposed to water stress. *J Bacteriol* 168:1036–1039.

Aoki, S. , Kondo, T. , and Ishiura, M. (1995) Circadian expression of the dnaK gene in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 177: 5606–5611.

Apte, S. K. , and Bhagawat, A. A. (1989) Salinity-stress-induced proteins in two nitrogen-fixing *Anabaena* strains differentially tolerant to salt. *J Bacteriol* 171: 909–915.

Apte, S. K. , Reddy B. P. , and Thomas, J. (1987) Relationship between sodium influx and salt tolerance of nitrogen fixing cyanobacteria. *Appl Environ Microbiol* 53:1934–1939.

Apte, S. K. , Fernandes, T. , Bardan, H. , and Ballal, A. (1998) Expression and possible role of stress-responsive proteins in *Anabaena*. *J Bio Sci* 23: 399–406.

Aran, M. , Ferrero, D. S. , Pagano, E. , and Wolosink, R. A. (2009) Typical 2-Cys peroxiredoxins-modulation by covalent transformations and noncovalent interactions. *Febs J* 276: 2478–2493.

Aravind, L. , and Ponting, C. P. (1999) The cytoplasmic helical linker domain of receptor histidine kinase and methyl-accepting proteins is common to many prokaryotic signaling proteins. *FEMS Microbiol Lett* 176:111-116.

Aravind, L. , Anantharaman, V. , and Iyer, L. M. (2003) Evolutionary connections between bacterial and eukaryotic signaling systems: A genomic perspective. *Curr Opin Microbiol* 6:490-507.

Argiëlles, J. C. (2000) Physiological roles of trehalose in bacteria and yeast: A comparative analysis. *Arch Microbiol* 174: 217-224.

Asada, K. (1994) Production and action of active oxygen species in photosynthesis tissues. In: Foyer, C. H. and Mullineaux, P. M. . (Eds.), *Causes of Photooxidative Stress and Amelioration of Defense Systems in Plants*. CRC Press, Boca Raton, Florida, FL., USA. pp. 77-104.

Asada, K. , and Takahashi, M. (1987) Production and scavenging of active oxygen photosynthesis. In: K yle, D. J., Osmond, C. B., and Arntzen, C. J. (Eds.) *Photoinhibition*, Elsevier Science Publishers , Amsterdam, The Netherlands, pp. 227-287.

Asada, K. , Yoshikawa, K. , Takahashi, M. , Maeda, Y. , and Enmanji, K. (1975) Superoxide dismutases from a blue-green alga, *Plectonema boryanum*. *J Biol Chem* 250:2801-2807.

Asadulghani Nitta, K. , Kaneko, Y. , Kojima, K. , Fukuzawa, H. , Kosaka, H. , and Nakamoto, H. (2004) Comparative analysis of the hspA mutant and wild-type *Synechocystis* sp. strain PCC 6803 under salt stress: Evaluation of the role of hspA in salt-stress management. *Arch Microbiol* 182: 487-497.

Asadulghani Suzuki, Y. , and Nakamoto, H. (2003) Light plays a role in the modulation of heat shock response in the cyanobacterium *Synechocystis* sp. PCC 6803. *Biochem Biophys Res Commun* 306: 872-879.

Atzenhofer, W. , Regelsberger, G. , Jacob, U. , Peschek, G. A. , Furtm ller, P. G. , and Obinger, C. (2002) The 2.0   resolution structure of the catalytic portion of a cyanobacterial membrane-bound manganese superoxide dismutase. *J Mol Biol* 321: 479-489.

Avenda o, M. C. , and Fern ndez-Valiente, E. (1994). Effect of sodium on phosphate uptake in unicellular and filamentous cyanobacteria. *Plant Cell Physiol* 35:1097-1101.

Av-Gay Y. , Aharonowitz, Y. , and Cohen, G. (1992) *Streptomyces* contains a 7.0 kDa cold shock like protein. *Nucleic Acids Res.* 20: 5478-5479.

Avonce, N. , Mendoza-Vargas, A. , Morett, E. , and Iturrig te, G. (2006) Insights on the evolution of trehalose biosynthesis. *BMC Evol Biol* 6:109. doi: 10.1186/1471-2148-6-109

Badger, M. R. , Price, G. D. , Long, B. M. , and Woodjer, F. J. (2006) The environmental plasticity and ecological genomics of the cyanobacterial CO₂ concentrating mechanism. *J Exp Bot (Phenotypic Plasticity and the Changing Environment-Special Issue)* 57:249-265.

Bagchi, S. N. , Bitz, T. , Pistorius, E. K. , and Michel, K. P. (2007) A *Synechococcus elongatus* PCC 7942 mutant with a higher tolerance toward the herbicide bentazone also confers resistance to sodium chloride stress. *Photosynth Res* 92: 87-101.

Bailey, S. , Silva, P. , Nixon, P. , Mullineaux, C. , Robinson, C. , and Mann, N. (2001) Auxiliary functions in photosynthesis: The role of the FtsH peptidase. *Biochem Soc Trans* 29: 455-459.

Balogi, Z. , Torok, Z. , Balogh, G. , J s vay K. , Shigapova, N. , Vierling, E. , Vigh, L. , and Horv th, I. (2005) "Heat shock lipid" in cyanobacteria during heat/light-acclimation. *Arch Biochem Biophys* 436: 346-354.

Bancroft, I. , and Smih, R. J. (1989) Restriction mapping of genomic DNA from five cyanophages infecting the heterocystous cyanobacteria *Nostoc* and *Anabaena*. *New Phytol* 113:161-166.

Bandaranayake, W. M. (1998) Mycosporines: are they nature's sunscreens? *Nat Prod Rep* 1998:159-171.

Bandyopadhyay S. , Starke, D. W. , Mieyal, J. J. , and Gronostajski, R. M. (1998) Thioltransferase (Glutaredoxin) reactivates the DNA-binding activity of oxidation inactivated nuclear factor I. *J Biol Chem* 273: 392-397.

Barker, M. , Boehm, M. , Nixon, P. J. , and Nield, J. (2008) Structural analysis of an FtsH2/FtsH3 complex isolated from *Synechocystis* sp. PCC 6803. In: Allen, J. F. , Gantt, E. , Golbeck, J. H. , and Osmond, B. . (Eds.) *Photosynthesis. Energy from the Sun*. 14th International Congress on Photosynthesis. Springer: The Netherlands, pp. 738-740.

Barker, M. , de Vries, R. , Nield, J. , Komenda, J. , and Nixon, P. J. (2006) The deg proteases protect *Synechocystis* sp. PCC 6803 during heat and light stresses but are not essential for removal of damaged D1 protein during the photosystem two repair cycle. *J Biol Chem* 281:30347-30355.

Barrett, A. J. . (Ed.) (1994) *Proteolytic Enzymes: Serines and Cysteine Peptidase*. *Methods Enzymol* 244: 765 pp. Academic Press Inc. San Diego, New York, Boston, London, Sydney, Tokyo and Toronto.

Barrett, A. J. . (Ed.) (1995) *Proteolytic Enzymes: Aspartic and Metallopeptidase*. *Methods Enzymol* 248: 870 pp. Academic Press Inc. San Diego, New York, Boston, London, Sydney, Tokyo and Toronto.

Basha, E. , Lee, G. J. , Bre ci, L. A. , Hausrath, A. C. , Buan, N. R. , Giese, K. C. , and Vierling, E. (2004) The identity of proteins associated with a small heat shock protein during heat stress in vivo indicates that these chaperones protect a wide range of cellular functions. *J Biol Chem* 279: 7566-7575.

Beebe, K. D. , Shin, J. , Peng, J. , Chaudhury C. , Khera, J. , and Pei, D. (2000) Substrate recognition through a PDZ domain in tail-specific peptidase. *Biochemistry* 39:3149-3155.

Bellem, S. , and Packer, L. (1988) Determination of pH gradients in intact cyanobacteria by electron spin resonance spectroscopy *Methods Enzymol* 167: 677-685.

Belnap, J. , B udel, B. , and Lange, O. L. (2001a) Biological soil crusts: Characteristics and distribution. In: Belnap, J. and Lange, O. L. . (Eds.) *Biological Soil Crusts: Structure, Function and Management*. *Ecol Studies* 15, Springer, Berlin, Germany pp. 3-30.

Belnap, J. , Rosentreter, R. , Leonard, S. , Kaltenecker, J. H. , Williams, J. , and Elridge, D. (2001b) Biological soil crusts: Ecology and Management. Technical Reference 1730-2, US Department of Interior.

Bernro tner, M. , Z m ck y, M. , Furtm ller, P. G. , Peschek, G. A. , and Obinger, C. (2009) Occurrence, phylogeny and function of catalases and peroxidases in cyanobacteria. *J Exp Bot* 60: 423-440. doi:10.1093/jxb/em309

Bewley J. D. (1979) Physiological aspects of desiccation tolerance. *Annu Rev Plant Physiol* 30:195-238.

Bhagawat, A. A. , and Apte, S. K. (1989) Comparative analysis of heat shock, salinity and osmotic stress in the nitrogen fixing cyanobacterium *Anabaena* sp. strain L-31. *J Bacteriol* 171: 5187-5189.

Bhattacharya, J. , Dastidar, K. G. , Chatterjee, A. , Majee, M. , and Majumdar, A. L. (2004) *Synechocystis* Fe superoxide dismutase gene confers oxidative stress tolerance to *Escherichia coli*. *Biochem Biophys Res Commun* 316: 540-544.

Bienert, R. , Baier, K. , Volkmer, R. , Lockau, W. , and Heinemann, U. (2006) Crystal structure of NblA from *Anabaena* sp. PCC 7120, a small protein playing a key role in phycobilisome degradation. *J Biol Chem* 281: 5216-5223.

Billi, D. , Friedmann, E. I. , Hofer, K. G. , Grilli Caiola, M. , and Ocampo-Friedmann, R. (2000) Ionizing-radiation resistance in the desiccation-tolerant cyanobacterium *Chroococcidiopsis*. *Appl Environ Microbiol* 66:1489-1492.

Billi, D. , Friedmann, I. , Helm, R. F. , and Potts, M. (2001) Gene transfer to the desiccation tolerant cyanobacterium *Chroococcidiopsis*. *J Bacteriol* 183: 2298-2305.

Billini, M. , Stamatakis, K. , and Sophianopoulou, V. (2008) Two members of a network of putative Na⁺/H⁺ antiporters are involved in salt and pH tolerance of the freshwater cyanobacterium *Synechococcus elongatus*. *J Bacteriol* 190: 6318-6329.

Blanco-Rivero, A. , Leganés, F. , Fernández-Valiente, E. , Calle, P. , and Fernández-Pinás, P. (2005a) *mrpA*, a gene with roles in resistance to Na⁺ and adaptation to alkaline pH in the cyanobacterium *Anabaena* sp. PCC 7120. *Microbiology* 151: 1671-1682. doi:10.1099/mic.0.27848.0

Blanco-Rivero, M. C. , Takabe, T. , and Viale, A. M. (2005b) Functional differences between cyanobacterial DnaKl chaperones from the halophyte *Aphanethece halophytica* and the freshwater species *Synechococcus elongatus* expressed in *Escherichia coli*. *Curr Microbiol* 51:164—170.

Blasius, M. , Hubscher, U. , and Sommer, S. (2008) *Deinococcus radiodurans*: What belongs to the survival kit? *Crit Rev Biochem Mol Biol* 43: 221-238.

Blumwald, E. , Mehlhorn, R.I. , and Packer, L. (1983) Studies on osmoregulation in salt adaptation of cyanobacteria with ESR spin-probe techniques. *Proe Nati Acad Sci USA* 80: 2599-2602.

Bohm, G. A. , Pfeleiderer, W. , Boger, P. , and Scherer, S. (1995) Structure of a novel oKgosaccharide-mycosporine-amino acid ultraviolet A/B sunscreen pigment from the terrestrial cyanobacterium, *Nostoc commune*. *J Biol Chem* 270: 8536-8539.

Borbély, G. , Surányi, G. , Korez, A. , and Pálfi, Z. (1985) Effect of heat shock on protein synthesis in the cyanobacterium *Synechococcus* sp. strain PCC 6301. *J Bacteriol* 161:1125-1130.

Boison, G. , Mergel, A. , Jolkver, H. , and Bothe, H. (2004) Bacterial life and dinitrogen fixation at a gypsum rock. *Appl Environ Microbiol* 70: 7070-7077.

Borowitzka, I. L. , Demmerle, S. , Mackay M. A. , and Norton, R. (1980) Carbon-13 nuclear magnetic resonance study of osmoregulation in a blue-green alga. *Science* 210: 650-651.

Bowler, C. , Van Camp, W. , Van Montagu, M. , and Inzé, D. (1994) Superoxide dismutase in plants. *CRC Critical Rev Plant Sci* 13:199-218.

Brand, J. J. (1977) Spectral changes in *Anacystis nidulans* induced by chilling. *Plant Physiol* 59: 970-973.

Brand, J. I. , Kirchanski, S. I. , and Ramirez-Mitchell, R. (1979) Chill-induced morphological alterations in *Anacystis nidulans* as a function of growth temperature. *Planta* 145: 63-68.

Brock, T. D. (1973) Lower pH limit for the existence of blue-green algae: evolutionary and ecological implications. *Science* 197: 480-483.

Brüll, L. P. , Huang, Z. , Thomas-Oates, J. E. , Paulsen, B. S. , Cohen, E. H. , and Michaelsen, T. E. (2000) Studies of polysaccharides from three edible species of *Nostoc* (cyanobacteria) with different colony morphologies: Structural characterization and effect on the complement system of polysaccharides from *Nostoc commune*. *J Phycol* 36: 871-881.

Bucca, G. , Brassington, A. M. , Hotchkiss, G. , Mersinias, V. , and Smith, C. P. (2003) Negative feedback regulation of *dnaK*, *clpB*, and *lon* expression by the DnaK chaperone machine in *Streptomyces coelicolor*, identified by transcriptome and in vivo DnaK-depletion analysis. *Mol Microbiol* 50:153-166.

Buchanan, B. B. , and Balmer, Y. (2005) Redox regulation: A broadening horizon. *Annu Rev Plant Biol* 56:187-220.

Büdel, B. , Weber, B. , Kuhl, M. , Pfanz, H. , Sültemeyer, D. , and Wessels, D. (2004) Reshaping of sandstone surfaces by cryptoendolithic cyanobacteria: bioalkalination causes chemical weathering in arid landscapes. *Geobiology* 2: 261-268.

Bukau, B. (1993) Regulation of the *Escherichia coli* heat-shock response. *Mol Microbiol* 9: 671-680.

Burnap, R. L. , Troyan, T. , and Sherman, L. A. (1993) The highly abundant chlorophyll-protein complex of iron-deficient *Synechococcus* sp. PCC 7942 (CP43') is encoded by the *isiA* gene. *Plant Physiol* 103: 893-902.

Cadoret, J.-C. , Demoulière, R. , Lavaud, I. , van Gorkom, H. I. , Houmard, I. , and Etienne, A.-L. (2004) Dissipation of excess energy triggered by blue light in cyanobacteria with CP43' (*isiA*). *Biochim Biophys Acta* 1659:100-104.

Callis, J. (1995) Regulation of protein degradation. *Plant Cell* 7: 845-857.

Campbell, D. , Zhou, G. , Gustafsson, P. , Öquist, G. , and Clarke, A. K. (1995) Electron transport regulates exchange of two forms of photosystem II D1 protein in the cyanobacterium *Synechococcus*. *Embo J* 14: 5457-5466.

Campbell, W. S. , and Laudenbach, D. E. (1995) Characterization of four superoxide dismutase genes from a filamentous cyanobacterium. *J Bacteriol* 177: 964-972.

Canini, A. , Civitareale, P. , Marini, S. , GriUi-Caiola, M. , and Rotilo, G. (1992) Purification of iron superoxide dismutase in the cyanobacterium *Anabaena cylindrica* Lemm and localization of the enzyme in heterocysts by immunogold labeling. *Planta* 187: 438-444.

Capitani, G. , Markovic-Housley Z. , DelVal, G. , Morris, M. , Jansonius, J. N. , and Schürmann, P. (2000) Crystal structures of two functionally different hioredoxins in spinach chloroplasts. *J Mol Biol* 302:135-154.

Castielli, O. , De La Cerda, B. , Navarro, J. A. , Hervás, M. , and De La Rosa, M. A. (2009) Proteome analyses of the response of cyanobacteria to different salt conditions. *FEBS Lett* 583:1753-1758. doi:10.1016/j.febslet.2009.03.069

Celerin, M. , Gilpin, A. A. , Schisler, N. I. , Ivanov, A. G. , Miskiewicz, E. , Krol, M. , and Laudenbach, D. E. (1998) ClpB in a cyanobacterium: Predicted structure, phylogenetic relationships and regulation by light and temperature. *J Bacteriol* 180: 5173-5182.

Cha, M. K. , Hong, S. K. , and Kim, I. H. (2007) Four thiol peroxidases contain a conserved GCT catalytic motif and act as a versatile array of lipid peroxidases in *Anabaena* sp. PCC 7120. *Free Radic Biol Med* 42:1736-1748.

Chae, H. Z. , Chung, S. I. , and Rhee, S.G. (1994) Thioredoxin-dependent peroxide reductase from yeast. *J Biol Chem* 269: 27670-27678.

Chae, H. Z. , Robison, K. , Poole, L. B. , Church, G. , Storz, G. , and Rhee, S. G. (1994) Cloning and sequencing of hiol-specific antioxidant from mammalian brain: Alkyl hydroperoxide reductase and hiol-specific antioxidant define a large family of antioxidant enzymes. *Proe Nati Acad Sci USA* 91: 7017-7021.

Chamot, D. , and Owtrim, G. W. (2000) Regulation of cold shock-induced RNA helicase gene expression in the cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 182:1251-1256.

Chamot, D. , Colvin, K. R. , Kujat-Choy, S. L. , and Owtrim, G. W. (2005) RNA structural rearrangement via unwinding and annealing by the cyanobacterial RNA helicase, CrhR. *J Biol Chem* 280: 2036-2044.

Chamot, D. , Magee, W. C. , Yu, E. , and Owtrim, G. W. (1999) A cold shock-induced cyanobacterial RNA helicase. *J Bacteriol* 181:1728-1732.

Chang, A. , Lin, R. , Studley, W. K. , Tran, C. , and Saier, Jr., M. (2004) Phylogeny as a guide to structure and function of membrane transport proteins. *Mol Membr Biol* 21:171-181.

Charles, S. A. , and Haliwell, B. (1980) Effect of hydrogen peroxide on spinách (*Spinacia oleracea*) chloroplast fructose biphosphatase. *Biochem J* 189:373-376.

Cheregi, O. , Sicora, C. , Kos, R. B. , Barker, M. , Nixon, P. J. , and Vass, I. (2007) The role of FtsH and Deg proteases in the repair of UV-B radiation-damaged photosystem II in the cyanobacterium *Synechocystis* PCC 6803. *Biochim Biophys Acta* 1767:820-828.

Chi, Z. , Su, C. D. , and Lu, W. D. (2007) A new exopolysaccharide produced by marine *Cyanothece* sp. 113. *Bioresource Technol* 98:1329-1332.

Chitnis, P. R. , and Nelson, L. (1991) Molecular cloning of the genes encoding two chaperone proteins of the cyanobacterium *Synechocystis* sp. PCC 6803. *J Biol Chem* 266: 58-65.

Choi, H. , Kim, S. , Mukhopadhyay, P. , Cho, S. , Woo, J. , Storz, G. , and Ryu, S. (2001) Structural basis of the redox switch in the OxyR transcription factor. *Cell* 105:103-113.

Claiborne, A. , and Fridovich, I. (1979) Purification of the O-dianisidine peroxidase from *Escherichia coli* B. *J Biol Chem* 254: 4245-4252.

Clarke, A. K. , and Eriksson, M.-J. (1996) The cyanobacterium *Synechococcus* sp. PCC 7942 possesses a close homologue to the chloroplast ClpC protein of higher plants. *Plant Mol Biol* 31: 721-730.

Clarke, A. K. , and Eriksson, M. J. (2000) The truncated form of bacterial heat shock protein ClpB/Hsp100 contributes to the development of thermotolerance in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 182: 7092-7096.

Clarke, A. K. , MacDonald, T. M. , and Sjogren, L. L. E. (2005) The ATP-dependent Clp protease in chloroplasts of higher plants. *Physiol Plant* 123: 406-412.

Clausen, T. , Southan, C. , and Ehrmann, M. (2002) The HtrA family of proteases: Implications for protein composition and cell fate. *Mol Cell* 10: 443-455.

Close, T. J. , and Lammers, P. J. (1993) An osmotic stress protein of cyanobacteria is immunologically related to plant dehydrins. *Plant Physiol* 101: 773-779.

Cockell, C. S. , Schuerger, A. C. , Bilk, B. , Friedmann, E. I., and Panitz, C. (2005) Effects of a simulated martian UV flux on the cyanobacterium *Chroococcidiopsis* sp. 029. *Astrobiology* 5:127-140.

Colin, J. , Jakopitsch, C. , Obinger, C. , and Iváncsik, A. (2010) The reaction of *Synechocystis* catalase-peroxidase (KatG) with isoniazid investigated by multifrequency (9-285 GHz) EPR spectroscopy *Appl Magn Reson* 37:267-277.

Collier, J. L. , and Grossman, A. R. (1995) Disruption of a novel thioredoxin-like protein alters the cyanobacterial photosynthetic apparatus. *J Bacteriol* 177: 3269-3276.

Cossins, A. R. (1994) Homeoviscous adaptation of biological membranes and its functional significance. In: Cossins, A. R. . (Ed.) *Temperature Adaptation of Biological Membranes*, Portland, London, UK. pp. 63-76.

Craig, E. A. , and Gross, C. A. (1991) Is hsp70 the cellular thermometer? *Trends Biochem Sci* 16:135-140.

Crowe, J. H. , Carpenter, J. E. , Crowe, L. M. , and Anchordoguy T. J. (1990) Are freezing and dehydration similar stress vectors? A comparison of modes of interaction of stabilizing solutes with biomolecules. *Cryobiology* 27:219-231.

Crowe, J. H. , Hoekstra, F. A. , and Crowe, L. M. (1989) Membrane phase transitions are responsible for imbibitional damage in dry pollen. *Proc Natl Acad Sci USA* 86: 520-523.

Crowe, J. H. , Hoekstra, F. A. , and Crowe, L. M. (1992) Anhydrobiosis. *Annu Rev Physiol* 54: 579-599.

Crowe, J. H. , Oliver, A. E. , and Tablin, F. (2002) Is there a single biochemical adaptation to anhydrobiosis. *Integr Comp Biol* 42:497-503.

Crowe, J. H. , Oliver, A. E. , Hoekstra, F. A. , and Crowe, L. M. (1997) Stabilization of dry membranes by mixtures of hydroxyethyl starch and glucose: The role of vitrification. *Cryobiology* 35: 20-30.

Crowley D. J. , and Hanawalt, P. C. (2001) The SOS-dependent upregulation of *uvrD* is not required for efficient nucleotide excision repair of ultraviolet light induced DNA photoproducts in *Escherichia coli*. *Mutat Res* 485:319-329.

Dartigalongue, C. , Missiakas, D. , and Raina, S. (2001) Characterization of the *Escherichia coli* sigma E regulon. *J Biol Chem* 276: 20866-20875.

Dasman Kajiyama, S. , Kawasaki, H. , Yagi, M. , Seki, T. , Fukusaki, E. , and Kobayashi, A. (2002a) *Paenibacillus glycanilyticus* sp. nov. a novel species that degrades heteropolysaccharide produced by the cyanobacterium *Nostoc commune*. *Int J Syst Evol Microbiol* 52:1669-1674. doi:10.1099/ijs.0.02171-0

Dasman Kajiyama, S. , Okazawa, A. , Fukusaki, E. , and Kobayashi, A. (2002b) Purification and properties of an enzyme capable of degrading the polysaccharide of the cyanobacterium *Nostoc commune*. *Z Naturforsch* 57:1042-1046.

Davis, D. A. , Newcomb, F. M. , Starke, D. W. , Ott, D. E. , Mieyal, J. J. , and Yarchoan, R. (1997) Thioltransferase (glutaredoxin) is detected within HIV-1 and can regulate the activity of glutathionylated HIV-1 protease in vitro. *J Biol Chem* 272: 25935-25940.

de Groot, A. , Chapon, V. , Servant, R. , Christen, R. , Fischer-Le Saux M. , et al. (2005) *Deinococcus deserti* sp. nov., a gamma-radiation-tolerant bacterium isolated from the Sahara Desert, *Int J Syst Evol Microbiol* 55: 2441-2446.

deGroot, A. , Dulerio, R. , Ortet, R. , Blanchard, L. , Guerin, R. , Fernandez, B. , Vacherie, B. , Dossat, C. , Jolivet, E. , Siguier, R. , Chandler, M. , Barakat, M. , Dedieu, A. , Barbe, V. , Heulin, T. , Sommer, S. , Achouak, W. , and Armengaud, J. (2009) Alliance of proteomics and genomics to unravel the specificities of Sahara bacterium *Deinococcus deserti*. *PLoS Genetics* 5: e1000434. doi: 1371/journal.pgen.1000434

de los Ríos, A. , Grube, M. , Sancho, L. G. , and Ascaso, C. (2007) Ultrastructural and genetic characteristics of endolithic biofilms colonizing Antarctic granite rocks. *FEMS Microbiol Ecol* 59:386-395.

de la Torre, J. R. , Goebel, B. M. , Friedmann, E. I. , and Páez N. R. (2003) Microbial diversity of cryptoendolithic communities from the McMurdo Dry Valleys, Antarctica. *Appl Environ Microbiol* 69: 3858-3867.

De Philippis, R. , and Vincenzini, M. (1998) Exocellular polysaccharides from cyanobacteria and their possible applications. *FEMS Microbiol Rev* 22:151-175.

De Philippis, R. , and Vincenzini, M. (2003) Outermost polysaccharide investments of cyanobacteria: Nature, significance and possible applications. *Recent Res Dev Microbiol* 7:13-22.

Derre, I. , Rapoport, G. , and Msadek, T. (1999) CtsR, a novel regulator of stress and heat shock response, controls *clp* and molecular chaperone gene expression in gram-positive bacteria. *Mol Microbiol* 31:117-131.

Deshnium, P. , Los, D. A. , Hayashi, H. , Mustardy L. , and Murata, N. (1995) Transformation of *Synechococcus* with a gene for *choK* enhances tolerance to salt. *Plant Mol Biol* 29: 897-907.

De Smet, K. A. , Weston, A. , Brown, I. N. , Young, D. B. , and Robertson, B. D. (2000) Three pathways for trehalose biosynthesis in mycobacteria. *Microbiology* 146:199-208.

De Virgilio, C. , Hottiger, T. , Dominguez, J. , Boiler, T. , and Wiemken, A. (1994) The role of trehalose synthesis for the acquisition of thermotolerance in yeast. I. Genetic evidence that trehalose is a thermoprotectant. *Eur J Biochem* 219:179-186.

Diamant, S. , Ben-Zvi, A. P. , Bukau, B. , and Goloubinoff, P. (2000) Size-dependent disaggregation of stable protein aggregates by the DnaK chaperone machinery *J Biol Chem* 275: 21107-21113.

Diamant, S. , Eliahu, N. , Rosenthal, D. , and Goloubinoff, P. (2001) Chemical chaperones regulate molecular chaperones in vitro and in cells under combined salt and heat stress. *J Biol Chem* 276: 39586-39591.

Dietz, K.-J. (2003) Plant peroxiredoxins. *Annu Rev Plant Biol* 54: 93-107.

Dietz, K.-J. (2011) Peroxiredoxins in plants and cyanobacteria. *Antioxidants Redox Signál* 15: 1129-1159. doi:10.1089/ars.2010.3657

Diner, B. A. , Ries, D. R. , Cohen, B. N. , and Metz, J. G. (1988) COOH-terminal processing of polypeptide D1 of the photosystem II reaction center of *Scenedesmus obliquus* is necessary for the assembly of the oxygen-evolving complex. *J Biol Chem* 263: 8972-8980.

Dines, M. , Sendersky E. , Schwarz, R. , and Adir, N. (2007) Crystallization of sparingly soluble stress-related proteins from cyanobacteria by controlled urea solubilization. *J Struct Biol* 158:116-121.

Donald, L- J. , Krokhin, O. V. , Duckworth, H. W. , Wiseman, B. , Deemagaran, T. , Singh, R. , Switala, J. , Carpena, X. , Fita, I. , and Loewen, P. C. C. (2003) Characterization of catalase-peroxidase KatG from *Burkholderia pseudomallei* by mass spectrometry *J Biol Chem* 278:35687-35692.

Dor, I. , and Paz, N. (1989) Temporal and spatial distribution of mat microalgae in the experimental solar ponds, Dead Sea area, Israel. In: Cohen, Y. , and Rosenberg, E. . (Eds.). *Microbial Mats: Physiological Ecology of Benthic Microbial Communities*. American Society for Microbiology Washington, DC., USA. pp. 114-122.

Dor, I. , Nehama, C. , and Baldinger, I. (1991) Polymorphism and salinity tolerance as a criterion for differentiation of three new species of *Chroococcidiopsis* (Chroococcales) *Arch Hydrobiol Algol Stud* 64: 411-421.

Dorman, C. J. (2006) DNA supercoiling and bacterial gene expression. *Sci Prog* 89:151-166.

Dougan, D. A. , Reid, B. G. , Horwich, A. L. , and Bukau, B. (2002) ClpS., a substrate modulator of the ClpAP machine. *Mol Cell* 9: 673-683.

Doyle, S. M. , Hoskins, J. R. , and Wickner, S. (2007) Collaboration between ClpB AAA+ remodeling protein and the DnaK chaperone system. *Proc Natl Acad Sci USA* 104:11138-11144.

Dufresne, A. , Salanoubat, M. , Partensky R. , Artiguenave, R. , Axmann, I. M. , Barbe, V. , Duprat, S. , Galperin, M. Y. , Koonin, E. V. , Le Gall, R. , Makarova, K. S. , Ostrowski, M. , Oztas, S. , Robert, C. , Rogozin, I. B. , Scanlan, D. J. , Tandeau de Marsac, N. , Weissenbach, J. , Wincker, P. , Wolf, Y. I. , and Hess, W. R. (2003) Genome sequence of the cyanobacterium *Prochlorococcus marinus* SS120, a nearly minimal oxyphototrophic genome. *Proc Natl Acad Sci USA* 100:10020-10025.

Dupont, C. L. , Barbeau, K. , and Palenik, B. (2008) Nickel uptake and limitation in marine *Synechococcus* strains. *Appl Environ Microbiol* 74: 23-31.

Dwivedi, K. , Sen A. , and Bullerjahn, G. S. (1997) Expression and mutagenesis of *dpsA* gene of *Synechococcus* sp. PCC 7942, encoding a DNA-binding protein involved in oxidative stress protection. *FEMS Microbiol Lett* 155: 85-91.

Eaton-Rye, J. J. , Shand, J. A. , and Nicoll, W. S. (2003) pH-dependent photoautotrophic growth of specific photosystem II mutants lacking lumenal extrinsic polypeptides in *Synechocystis* PCC 6803. *FEBS Lett* 543:148-153.

Edwards, H. G. M. , Villar, S. E. I. , Parnell, I. , Cockell, C. S. , and Lee, P. (2005) Raman spectroscopic analysis of cyanobacterial gypsum halotrophs and relevance for sulphate deposits on Mars. *Analyst* 130: 917-923.

Ehira, S. , Hamano, T. , Hayashida, T. , Kojima, K. , Nakamoto, H. , Hiyama, T. , Ohmori, M. , Shivaji, S. , and Sato, N. (2003) Conserved temperature-dependent expression of RNA-binding proteins in the cyanobacteria with different temperature optima. *FEMS Microbiol Lett* 225:137-142.

Ehling-Schulz, M. , Bilger, W. , and Scherer, S. (1997) UV-B-induced synthesis of photoprotective pigments and extracellular polysaccharides in the terrestrial cyanobacterium *Nostoc commune*. *J Bacteriol* 179:1940-1945.

Eitinger, T. (2004) In vivo production of active nickel superoxide dismutase from *Prochlorococcus marinus* MIT9313 is dependent on its cognate peptidase. *J Bacteriol* 186: 7821-7825.

Eklund, H. , Cambillau, C. , Sjöberg, B. M. , Holmgren, A. , Jornvall, H. , Hoog, J. O. , and Branden, C. I. (1984) Conformational and functional similarities between glutaredoxin and thioredoxins. *Embo J* 3:1443-1449.

Eklund, H. , Gleason, F. K. , and Holmgren, A. (1991) Structural and functional relations among thioredoxins of different species. *Proteins Struct Funct Genet* 11:13-28.

Elanskaya, I. V. , Karandashova, I. V. , Bogachev, A. V. , and Hagemann, M. (2002) Functional analysis of the Na⁺/H⁺ antiporter encoding genes of the cyanobacterium *Synechocystis* sp. PCC 6803. *Biochemistry (Moscow)* 67: 432-440.

Elbein, A. D. (1974) The metabolism of α,α -trehalose. *Adv Carb Chem Biochem* 30: 227-256.

Elbein, A. D. , Pan, Y. T. , Pastuszak, I. , and Carroll, D. (2003) New insights on trehalose: a multifunctional molecule. *Glycobiology* doi:10.1093/glycob/cwg047

El Bissati, K. , and Kirilovsky D. (2001) Regulation of *psbA* and *psaE* expression by light quality in *Synechocystis* species PCC 6803. A redox control mechanism. *Plant Physiol* 125:1988-2000.

El-Fahmawi, B. , and Owttrim, G. W. (2003) Polar-biased localization of the cold stress-induced RNA helicase, CrhC., in the cyanobacterium *Anabaena* sp. strain PCC 7120. *Mol Microbiol* 50:1439-1448.

Ellis, R. J. (1990) The molecular chaperone concept. *Setrin Cell Biol* 1:1-9.

Elridge, D. I. , and Greene, R. S. B. (1994) Microbial soil crusts: A review of their roles in soil and ecological processes in the range lands of Australia. *J Soil Res* 32: 389-415.

Elridge, D. I. , and Greene, R. S. B. (1994) Microbial soil crusts: A review of their roles in soil and ecological processes in the range lands of Australia. *J Soil Res* 32: 389-415.

Elridge, D. I. , and Greene, R. S. B. (1994) Microbial soil crusts: A review of their roles in soil and ecological processes in the range lands of Australia. *J Soil Res* 32: 389-415.

Enami, I. , Kikuchi, S. , Fukuda, T. , Ohta, H. , and Shen, J. R. (1998) Binding and functional properties of four extrinsic proteins of photosystem II from a red alga *Cyanidium caldarium*, as studied by release-reconstitution experiments. *Biochemistry* 37:2787-2793.

Engelbrecht, E. , Marin, K. , and Hagemann, M. (1999) Expression of *ggps* gene, involved in osmolyte synthesis in the marine cyanobacterium *Synechococcus* sp. strain PCC 7002, revealed regulatory differences between this strain and the freshwater strain *Synechocystis* sp. strain PCC 6803. *Appl Environ Microbiol* 65: 4822-4829.

Erbse, A. , Schmidt, R. , Bornemann, T. , Schneider-Mergener, I. , Mogk, A. , Zahn, R. , Dougan, D. A. , and Bukau, B. (2006) ClpS is an essential component of the N-end rule pathway in *Escherichia coli*. *Nature (London)* 439b: 753-756.

Erdmann, N. , Fulda, S. , and Hagemann, M. (1992) Glucosylglycerol accumulation during salt acclimation of two unicellular cyanobacteria. *J Gen Microbiol* 138:363-368.

Eriksson, M.-J. , and Clarke, A. K. (1996) The heat shock protein ClpB mediates the development of thermotolerance in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 178: 4839-4846.

Eriksson, M.I. , Schelin, I. , Miskiewicz, E. , and Clarke, A. K. (2001) Novel form of ClpB/Hsp 100 protein in the cyanobacterium *Synechococcus*. *J Bacteriol* 183: 7392-7396.

Espie, G. S. , Miller, A. G. , and Calvin, D. T. (1988) Characterization of the Na⁺ requirement in cyanobacterial photosynthesis. *Plant Physiol* 88: 757-763.

Fahey R. C. , and Sundquist, A. R. (1991) Evolution of glutathione metabolism. *Adv Enzymol Relat Areas Mol Biol* 64:1-53.

Fahey R. C. , Brown, W. C. , Adams, W. B. , and Worsham, M. B. (1978) Occurrence of glutathione in bacteria. *J Bacteriol* 133: 1126-1129.

Fang, S. , and Barnum, S. P. (2003) The heat shock gene, *hspG*, and thermotolerance in the cyanobacterium *Synechocystis* sp. PCC 6803. *Curr Microbiol* 47: 341-346.

Ferjani, A. , Mustardy L. , Sulpice, R. , Marin, K. , Suzuki, I. , Hagemann, M. , and Murata, N. (2003) Glucosylglycerol, a compatible solute sustains cell division under salt stress. *Plant Physiol* 131:1628-1637.

Fernandes, A. , and Holmgren, A. (2004) Glutaredoxins: Glutathione-dependent redox enzymes with functions far beyond a simple thioredoxin back up system. *Antioxid Redox Signal* 6: 63-74.

Ferreira, A. C. , Nobre, M. E. , Rainey F. A. , Silva, M. T. , Wait, R. , et al. (1997) *Deinococcus geothermalis* sp. nov. and *Deinococcus murrayi* sp. nov, two extremely radiation resistant and slightly thermophilic species from hot springs. *Int J Syst Bacteriol* 47: 939-947.

Fleming, E. D. , and Castenholz, R.W. (2007). Effects of periodic desiccation on the synthesis of the UV-screening compound, scytonemin, in cyanobacteria. *Environ Microbiol* 9:1448-1455.

Florencio, F. J. , Pérez-Pérez, M. E. , Lopez-Maury L. , Mata-Cabana, A. , and Lindahl, M. (2006) The diversity and complexity of the cyanobacterial thioredoxin systems. *Photosynth Res* 89:157-171.

Florian, H. P. , Holger, S. , and Iwona, A. (2005) The family of Deg proteases in cyanobacteria and chloroplasts of higher plants. *Physiol Plant* 123: 413-420.

Forkl, H. , Vandekerckhove, J. , Drews, G. , and Tadros, M. H. (1993) Molecular cloning, sequence analysis and expression of the gene for catalase-peroxidase (*cpeA*) from the photosynthetic bacterium *Rhodobacter capsulatus* BIO. *Eur J Biochem* 214: 251-258.

Forrest H. S. , Van Baalen, C. , and Myers, J. (1957) Occurrence of pteridines in a blue-green alga. *Science* 125: 699-700.

Foster, J. S. , Havemann, S. A. , Singh, A. K. , and Sherman, L. A. (2009) Role of *mrgA* in peroxide and light stress in the cyanobacterium *Synechocystis* sp. PCC 6803. *FEMS Microbiol Lett* 293:298-304(7).

Fourquet, S. , Huang, M. E. , D'Autreaux, B. , and Toledano, M. B. (2008) The dual functions of hsp100-based peroxidases in H2O2 scavenging and signaling. *Antioxid Redox Signal* 10:1565-1576.

Foyer, C. H. , and Harbinson, J. (1994) Oxygen metabolism and the regulation of photosynthetic electron transport. In: Foyer, C. H. , and Mullineaux, P. M. . (Eds.) *Causes of Photooxidative Stress and Amelioration of Defense Systems in Plants*: CRC Press, Boca Raton, Florida, FL., USA. pp. 1-42.

Fraser, C. M. , Casjens, S. , Huang, W. M. , Sutton, G. G. , Rebecca Clayton, R. , Lathigra, R. , White, O. , Ketchum, K. A. , Dodson, R. , Hickey E. K. , Gwinn, M. , Dougherty B. , Tomb, J- F. , Fleischmann, R. D. , Richardson, D. , Peterson, J. , Kerlavage, A. R. , Quackenbush, J. , Salzberg, S. , Hanson, M. , van Vugt, R. , Palmer, N. , Adams, M. D. , Gocayne, J. , Weidman, J. , Utterback, T. , Watthey L. , McDonald, L. , Artiach, P. , Bowman, C. , Garland, S. , Fujii, C. , Cotton, M. D. , Horst, K. , Roberts, K. , Hatch, B. , Smith, H. O. , and Venter, J. C. (1997) Genomic sequence of a Lyme disease spirochaete, *Borrelia burgdorferi*. *Nature (London)* 390: 580-586. doi:10.1038/37551

Fraser, C. M. , Norris, S. J. , Weinstock, G. M. , White, O. , Sutton, G. G. , Dodson, R. , Gwinn, M. , Hickey E. K. , Clayton, R. , Ketchum, K. A. , Sodergren, E. , Hardham, J. M. , McLeod, M. P. , Salzberg, S. , Peterson, J. , Khalak, H. , Richardson, D. , Howell, J. K. , Chidambaram, M. , Utterback, T. , McDonald, L. , Artiach, P. , Bowman, C. , Cotton, M. D. , Fujii, C. , Garland, S. , Hatch, B. , Horst, K. , Roberts, K. , Sandusky M. , Weidman, J. , Smith, H. O. , and Venter, J. C. (1998) Complete Genome Sequence of *Treponema pallidum*, the syphilis spirochete. *Science* 281: 375-388. doi:10.1126/science.281.5375.375

Fridovich, I. (1989) Superoxide dismutases, an adaptation to a paramagnetic gas. *J Biol Chem* 264: 7761-7764.

Fridovich, I. (1995) Superoxide radical and superoxide dismutases. *Annu Rev Biochem* 64: 97-112.

Fridovich, I. (1997) Superoxide anion radical (O₂^{•-}). Superoxide dismutases and related matters. *J Biol Chem* 271: 18515-18517.

Friedmann, E. I. (1961) *Chroococcidiopsis kashaïi* sp. nov. and the genus *Chroococcidiopsis* (studies on cave algae from Israel III). *Osterr Bot Z* 108: 354-367.

Friedmann, E. I. , and Ocampo-Friedmann, R. (1995) A primitive cyanobacterium as pioneer microorganism for terraforming Mars. *Adv Space Res* 15:243-246.

Friedmann, E.I. , Hua, M. , and Ocampo-Friedmann, O. (1988) Cryptoendolithic lichen and cyanobacterial communities of the Ross Desert, Antarctica. *Polarforschung* 58: 251-259.

Friedmann, E. I. , Kappen, L. , Meyer, M. A. , and Nienow, J. A. (1993) Long-term productivity in the cryptoendolithic microbial community of the Ross Desert, Antarctica. *Microb Ecol* 25: 51-69.

Friedrich, K. L. , Giese, K. C. , Buan, N. , and Vierling, E. (2004) Interactions between small heat shock protein subunits and substrate in small heat shock protein-substrate complexes. *J Biol Chem* 279:1080-1089.

Fukumori, Y. , Fujiwara, T. , Okada-Takahashi, Y. , Mukohata, Y. , and Yamanaka, T. (1985) Purification and properties of a peroxidase from *Halobacterium halobium* L-33. *J Biochem* 98:1055-1061.

Fuangthong, M. , Herbig, A. F. , Bsat, N. , and Helmann, J. D. (2002) Regulation of the *Bacillus subtilis* *fur* and *perR* genes by PerR: not all members of the PerR regulon are peroxide inducible. *J Bacteriol* 184:3276-3286.

Fulda, S. , Huang, F. , Nilsson, F. , Hagemann, M. , and Norling, B. (2000) Proteomics of *Synechocystis* sp. strain PCC 6803. Identification of periplasmic proteins in cells grown at low and high salt concentrations. *Eur J Biochem* 267: 5900-5907.

Fulda, S. , Mikkat, S. , Schroder, W. , and Hagemann, M. (1999) Isolation of salt-induced periplasmic proteins from *Synechocystis* sp. strain PCC 6803. *Arch Microbiol* 171: 214-217.

Fulda, S. , Mikkat, S. , Huang, F. , Huckauf, J. , Marin, K. , Norling, B. , and Hagemann, M. (2006) Proteome analysis of salt stress response in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *Proteomics* 6:2733-2745.

Fuller-Pace, F. V. (1994) RNA helicases: modulators of RNA structure. *Trends Cell Biol* 4:271-274.

Fuller-Pace, F. V. (2006) DEXD/H box RNA helicases: multifunctional proteins with important roles in transcriptional regulation. *Nucleic Acids Res* 34:4206-4215.

Fuller-Pace, F.V. , Nicol, S. M. , Reid, A. D. , and Lané, D. P. (1993) DbpA: a DEAD box protein specifically activated by 23s rRNA. *Emboj*. 12:3619-3626.

Furuki, M. , Tanaka, N. , Hiyama, T. , and Nakamoto, H. (1996) Cloning, characterization and functional analysis of groEL-like gene from thermophilic cyanobacterium *Synechococcus vulcanus*, which does not form an operon with groES. *Biochim Biophys Acta* 1294:106-110.

Gaber, A. , El-Awady, M. , Elarabi, N. I. , and Soliman, M. H. (2007) Overexpression of glutaredoxin-2 from cyanobacterium *Synechocystis* PCC 6803 in *Escherichia coli* conferring enhanced salt tolerance. *Arab J Biotechnol* 10:13-22.

García-Domínguez, M. , and Florencio, F. J. (1997) Nitrogen availability and electron transport control the expression of *oiglnB* gene (encoding PII protein) in the cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Mol Biol* 35: 723-734.

García-Pichel, R. , López-Cortés, A. , and Núbel, U. (2001) Phylogenetic and morphological diversity of cyanobacteria in soil desert crusts from the Colorado plateau. *Appl Environ Microbiol* 67:1902-1910.

Gardner, P. R. , and Fridovich, I. (1991) Superoxide sensitivity of the *Escherichia coli* 6-phosphogluconate dehydratase. *J Biol Chem* 266:1478-1483.

Gaff, D. R. (1997) Response of desiccation tolerant "resurrection" plants to water stress. In: Basra, A. S. and Basra, R. K. . (Eds.) *Mechanisms of Environmental Stress Resistance in Plants*. Harwood Academic Publishers, London, UK. pp. 43-58.

Gao, K. S. (1998) Chinese studies on the edible blue-green alga, *Nostoc flagelliforme*: A review. *J Appl Phycol* 10: 37-49.

Gerrah, J. R. , Gerrath, J. A. , and Larson, D. W. (1995) A preliminary account of the endolithic algae of Kmetstone cliffs of the Niagara Escarpment. *Can J Bot* 73: 788-793.

Gerrath, J. R. , Gerrah, J. A. , Matthes, U. , and Larson, D. W. (2000) Endolithic algae and cyanobacteria from cliffs of the Niagara Escarpment, Ontario, Canada. *Can J Bot* 78: 807-815.

Getzoff, E. D. , Cabelli, D. E. , Fisher, C. L. , Parge, H. E. , Viezzoll, S. M. , Banèi, L. , and Hallewell, R. A. (1992) Faster superoxide dismutase mutants designed by enhancing electrostatic guidance. *Nature (London)* 358: 347-351.

Giese, K. C. , and Vierling, E. (2002) Changes in oligomerization are essential for the chaperone activity of a small heat shock protein in vivo and in vitro. *J Biol Chem* 277: 46310-46318.

Giovanna, R. , Cella, R. , Camerino, G. , and Ciferri, O. (1983) Resistance to azetidine-2-carboxylic acid and sodium chloride tolerance in carrot cell cultures and *Spirulina platensis*. *Plant Cell Physiol* 24:1073-1078.

Glatz, A. , Horváth, I. , Varvasovszki, V. , Kovács, E. , Torok, Z. , and Vigh, L. (1997) Chaperonin genes of the *Synechocystis* PCC 6803 are differentially regulated under light-dark transition during heat stress. *Biochem Biophys Res Commun* 239: 291-297.

Glatz, A. , Vass, I. , Los, D. A. , and Vigh, L. (1999) The *Synechocystis* model of stress: From molecular chaperones to membranes. *Plant Physiol Biochem* 37:1-12.

Gleason, R. K. (1990) Function of two dissimilar thioredoxins in the cyanobacterium, *Anabaena* sp. 7120. In: Baltscheffsky M. . (Ed.) *Current Research in Photosynthesis*, vol. 4, Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 175-178.

Gleason, R. K. (1992) Activities of two dissimilar thioredoxins from the cyanobacterium *Anabaena* sp. PCC 7120. *J Bacteriol* 174: 2592-2598.

Gleason, R. K. , Whittaker, M. M. , Holmgren, A. , and Jornvall, H. (1985) The primary structure of thioredoxin from the filamentous cyanobacterium *Anabaena* sp. 7119. *J Biol Chem* 260: 9567-9573.

Golden, S. S. (1995) Light-responsive gene expression in cyanobacteria. *J Bacteriol* 177:1651-1654.

Golden, S. S. , Brusslan, J. , and Haselkorn, R. (1986) Expression of a family of *oipbA* genes encoding a photosystem II polypeptide in the cyanobacterium *Anacystis nidulans* R2. *Embo J* 5:2789-2798.

Goloubinoff, R. , Mogk, A. , Zvi, A. R. , Tomoyasu, T. , and Bukau, B. (1999) Sequential mechanism of solubilization and refolding of stable protein aggregates by a chaperone network. *Proc Natl Acad Sci USA* 96:13732-13737.

Gombos, Z. , Kanervo, E. , Tsvetkova, N. , Sakamoto, T. , Aro, E.-M. , and Murata, N. (1997) Genetic enhancement of the ability to tolerate photoinhibition by introduction of unsaturated bonds into membrane glycerolipids. *Plant Physiol* 115: 551-559.

Gombos, Z. , Wada, H. , and Murata, N. (1992) Unsaturation of fatty acids in membrane lipids enhances tolerance of the cyanobacterium *Synechocystis* PCC 6803 to low temperature photoinhibition. *Proc Natl Acad Sci USA* 99: 9959-9963.

Gong, H. , Tang, Y. , Wang, J. , Wen, X. , Zhang, L. , and Lu, C. (2008) Characterization of photosystem II in salt-stressed cyanobacterial *Spirulina platensis* cells. *Biochim Biophys Acta* 1777:488-495.

Gorbalenya, A. E. , and Koonin, E. V. (1993) Helicases: amino acid sequence comparisons and structure-function relationships. *Curr Opin Struct Biol* 3:419-429.

Gorman, A. A. , and Rodgers, M. A. (1992) Current perspectives of singlet oxygen detection in biological environments. *J Photochem Photobiol* 14:159-176.

Gottesman, S. , and Maurizi, M. R. (1992) Regulation by proteolysis: Energy-dependent proteases and their targets. *Microbiol Rev* 56: 592-621.

Graumann, R. L. , and Marahiel, M. A. (1996) Some like it cold: Response of microorganisms to cold shock. *Arch Microbiol* 166: 293-300.

Graumann, R. L. , and Marahiel, M. A. (1998) A superfamily of proteins that contain the cold shock domain. *Trends Biochem Sci* 23: 286-290.

Graumann, P. L. , Schröder, K. , Schmid, R. , and Marahel, M. M. (1996) Cold shock stress-induced proteins in *Bacillus subtilis*. *J Bacteriol* 178: 4611-4619.

Grilli Caiola, M. , Billi, D. , and Friedmann, E. I. (1996) Effect of desiccation on envelopes of the cyanobacterium *Chroococcidiopsis* sp. (*Chroococcales*). *Eur J Phycol* 31: 97-105.

Grilli Caiola, M. , Ocampo-Friedmann, R. , and Friedmann, E. I. (1993) Cytology of long-term desiccation in the desert cyanobacterium *Chroococcidiopsis* sp. (*Chroococcales*). *Phycologia* 32: 315-322.

Grimaud, R. , Kessel, M. , Beuron, F. , Steven, A. C. , and Maurizi M.R. (1998) Enzymatic and structural similarities between the *Escherichia coli* ATP-dependent proteases ClpXP and ClpAP. *J Biol Chem* 273:12476-12481.

Gruber, M. Y. , Glick, B. R. , and Thompson, J. E. (1990) Cloned manganese superoxide dismutase reduces oxidative stress in *Escherichia coli* and *Anacystis nidulans*. *Proc Natl Acad Sci USA* 87: 2608-2612.

Gu, L. , Abulimiti, A. , Li, W. , and Chang, Z. (2002) Monodisperse Hsp 16.3 nonamer exhibits dynamic association and reassociation, with the nonamer dissociation prerequisite for chaperone-Kke activity *J Mol Biol* 319: 517-526.

Gualerzi, C. O. , Giuliadori, A. M. , and Pon, C. L. (2003) Transcriptional and post-transcriptional control of cold shock genes. *J Mol Biol* 331: 527-539.

Gutteridge, J. M. C. , and Halliwell, B. (1990) The measurement and mechanism of lipid peroxidation in biological systems. *Trends Biochem Sci* 15:129-135.

Hagemann, M. (2011) Molecular biology of cyanobacterial salt acclimation. *FEMS Microbiol Rev* 35:87-123. doi: 10.1111/j.1574-6976.2010.00234.x

Hagemann, M. , and Erdmann, N. (1994) Activation and pathway of glucosylglycerol synthesis in the cyanobacterium *Synechocystis* sp. PCC 6803. *Microbiology* 140:1427-1431.

Hagemann, M. , and Erdmann, N. (1997) Environmental stresses. In: Rai, A.K. (Ed.) *Cyanobacterial Nitrogen Metabolism and Environmental Biotechnology*. Springer-Verlag, Heidelberg; Narosa Publishing House, New Delhi, pp. 156-221.

Hagemann, M. , and Zuther, E. (1992) Selection and characterization of mutants of the cyanobacterium *Synechocystis* sp. PCC 6803 unable to tolerate high salt concentrations. *Arch Microbiol* 158:429-434.

Hagemann, M. , Erdmann, N. , and Wittenburg, E. (1987) Synthesis of glucosylglycerol in salt-stressed cells of the cyanobacterium *Microcystis firma*. *Arch Microbiol* 148: 275-279.

Hagemann, M. , Schoor, A. , Jeanjean, R. , Zuther, E. , and Joset, F. (1997) The *stpA* gene from *Synechocystis* sp. strain PCC 6803 encodes the glucosylglycerol-phosphate phosphatase involved in cyanobacterial osmotic response to salt shock. *J Bacteriol* 179:1727-1733.

Hagemann, M. , Schoor, A. , Mikkat, S. , Effmert, U. , Zuther, E. , Marin, K. , Fulda, S. , Vinnemeier, J. , Kunert, A. , Milkowski, C. , Probst, C. , and Erdmann, N. (1999) The biochemistry and genetics of the synthesis of osmoprotective compounds in cyanobacteria. In: Oren, A. . (Ed.) *Microbiology and Biogeochemistry of Hypersaline Environments*. CRC Press, Boca Raton, FL., USA. pp. 177-186.

Hagemann, M. , Techel, D. , and Rensing, L. (1991) Comparison of salt- and heat-induced alterations of protein synthesis in the cyanobacterium *Synechocystis* sp. PCC 6803. *Arch Microbiol* 155: 587-592.

Hagemann, M. , Wolfel, L. , and Krüger, B. (1990) Alterations of protein synthesis in the cyanobacterium *Synechocystis* sp. PCC 6803 after a salt shock. *J Gen Microbiol* 136:1393-1399.

Halliwell, B. , and Gutteridge, J. M. C. (1986) Oxygen free radicals and iron in relation to biology and medicine: Some problems and concepts. *Arch Biochem Biophys* 246: 501-514.

Halliwell, B. , and Gutteridge, J. M. C. (1989) *Free Radicals in Biology and Medicine*. Clarendon Press, Oxford, UK.

Halí, A. , Karplus, P. A. , and Poole, L. B. (2009) Typical 2-Cys peroxiredoxins-structure, mechanisms and functions. *Febs J* 276: 2469-2477.

Hamano, T. , Murakami, S. , Takayama, K. , Ehira, S. , Maruyama, K. , Kawakami, H. , Morita, E. H. , Hayashi, H. , and Sato, N. (2004) Characterization of RNA-binding properties of three types of RNA-binding proteins in *Anabaena* sp. PCC 7120. *Cell Mol Biol* 50: 613-624.

Hara, H. , Yamamoto, Y. , Higashitani, A. , Suzuki, H. , and Nishimura, Y. (1991) Cloning, mapping, and characterization of the *Escherichia coli* *prc* gene, which is involved in C-terminal processing of penicillin-binding protein 3. *J Bacteriol* 173: 4799-4813.

Harel, Y. , Ohad, I. , and Kaplan, A. (2004) Activation of photosynthesis and resistance to photoinhibition in cyanobacteria within biological desert crust. *Plant Physiol* 136: 3070-3079.

Haranczyk, H. , Gazdzinski, S. , and Olech, M. (1998) Initial stages of lichen hydration observed by proton magnetic relaxation. *New Phytol* 138:191-202.

Harrison, C. (2003) GrpE, a nucleotide exchange factor for DnaK. *Cell Stress Chaperones* 8:218-224.

Hartl, F. U. , and Hayer-Hartl, M. (2002) Molecular chaperones in the cytosol: From nascent chain to folded protein. *Science* 295:1852-1858.

Haslbeck, M. , Walke, S. , Stromer, T. , Ehrnsperger, M. , White, H. E. , Chen, S. , Saibil, H. R. and Buchner, J. (1999) Hsp26: a temperature-regulated chaperone. *Embo J* 18: 6744-6751.

Hausuhl, K. , Andersson, B. , and Adamska, I. (2001) A chloroplast DegP2 protease performs the primary cleavage of the photodamaged D1 protein in plant photosystem II. *Embo J* 20: 713-722.

Havaux, M. , Guedeney, G. , Hagemann, M. , Yermenko, N. , Matthijs, H. C. , and Jeanjean, R. (2005) The chlorophyll-binding protein IsiA is inducible by high light and protects the cyanobacterium *Synechocystis* PCC 6803 from photooxidative stress. *FEBS Lett.* 579:2289-2293.

Hecker, M. , Schumann, W. , and Volker, U. (1996) Heat-shock and general stress response in *Bacillus subtilis*. *Mol Microbiol* 19:417-428.

Heering, H. A. , Indriani, C. , Regelsberger, G. , Jalopitsch, C. , Obinger, C. , and Smulevich, G. (2002) New insights into the heme cavity structure of catalase-peroxidase, a spectroscopic approach to the recombinant *Synechocystis* enzyme and selected distal cavity mutants. *Biochemistry* 41: 9237-9247.

Helm, R. R. , Huang, Z. , Edwards, D. , Leeson, H. , Peery W. , and Potts, M. (2000) Structural characterization of the released polysaccharide of desiccation-tolerant *Nostoc commune* DRH1. *J Bacteriol* 182: 974-982.

Helmann, J. D. , Wu, M. R. , Kobel, P. A. , Gamo, F. J. , Wilson, M. , Morshedi, M. M. , Navre, M. , and Paddon, C. (2001) Global transcriptional response of *Bacillus subtilis* to heat shock. *J Bacteriol* 183: 7318-7328.

Helmann, J. D. , Wu, M. R. , Gaballa, A. , Kobel, P. A. , Morshedi, M. M. , Fawcett, P. , and Paddon, C. (2003) The global transcriptional response of *Bacillus subtilis* to peroxide stress is coordinated by three transcription factors. *J Bacteriol* 185: 243-253.

Herbert, S. K. , Samson, G. , Fork, D. C. , and Laudenbach, D. E. (1992) Characterization of damage to photosystems I and II in a cyanobacterium lacking detectable iron superoxide dismutase activity *Proc Natl Acad Sci USA* 89: 8716-8720.

Herbig, A. R. , and Helmann, J. D. (2001) Roles of metal ions and hydrogen peroxide in modulating the interaction of the *Bacillus subtilis* PerR peroxide regulon repressor with operator DNA. *Mol Microbiol* 41: 849-859.

Herman, C. , Thevenet, D. , D'Ari, R. , and Boulloc, P. (1995) Degradation of sigma 32, the heat stress regulator in *Escherichia coli*, is governed by HflB. *Proc Natl Acad Sci USA* 92: 3516-3520.

Herranen, M. , Battchikova, N. , Zhang, P. , Graf, A. , Sirpio, S. , Paakkarinen, V. , and Aro, E.-M. (2004) Towards functional proteomics of membrane protein complexes in *Synechocystis* sp. PCC 6803. *Plant Physiol* 134: 470-481.

Hibino, T. , Kaku, N. , Yoshikawa, H. , Takabe, T. , and Takabe, T. (1999) Molecular characterization of DnaK from the halotolerant cyanobacterium *Aphanotece halophytica* for ATPase, protein folding and copper binding under various salinity conditions. *Plant Mol Biol* 40:409-418.

Higo, A. , Ikeuchi, M. , and Ohmori, M. (2008) cAMP regulates respiration and oxidative stress during rehydration in *Anabaena* sp. PCC 7120. *FEBS Lett* 582:1883-1888.

Higo, A. , Katoh, H. , Ohmori, K. , Ikeuchi, M. , and Ohmori, M. (2006) The role of a gene cluster for trehalose metabolism in dehydration tolerance of the filamentous cyanobacterium *Anabaena* sp. PCC 7120. *Microbiology* 152: 979-987.

Higo, A. , Suzuki, T. , Ikeuchi, M. , and Ohmori, M. (2007) Dynamic transcriptional changes in response to rehydration in *Anabaena* sp. PCC 7120. *Microbiology* 153: 3685-3694. doi:10.1099/mic.0.2007/009223-0

Higgins, C. R. , Dorman, C. J. , Stirrington, D. A. , Waddell, L. , Booth, I. R. , May, G. , and Bremer, E. A. (1988) Physiological role for DNA supercoiling in the osmotic regulation of gene expression in *S. typhimurium* and *E. coli*. *Cell* 52: 569-584.

Hihara, Y. , Kamei, A. , Kanehisa, M. , Kaplan, A. , and Ikeuchi, M. (2001) DNA microarray analysis of cyanobacterial gene expression during acclimation to high light. *Plant Cell* 13: 793-806.

Hill, D. R. , Hladun, S. L. , Scherer, S. , and Potts, M. (1994a) Water stress proteins of *Nostoc commune* (Cyanobacteria) are secreted with UV-A/B-absorbing pigments and associate with 1,4-p-D-xylanxylanohydrolase activity. *J Biol Chem* 269: 7726-7734.

Hill, D. R. , Keenan, T. W. , Helm, R. R. , Potts, M. , Crowe, L. M. , and Crowe, J. H. (1999) Extracellular polysaccharide of *Nostoc commune* (cyanobacteria) inhibits fusion of membrane vesicles during desiccation. *J Appl Phycol* 9: 237-248.

Hill, D. R. , Peat, A. , and Potts, M. (1994b) Biochemistry and structure of glycan secreted by desiccation-tolerant *Nostoc commune* (cyanobacteria). *Protoplasma* 182:126-148.

Hill, J. H. , Penny, S. L. , Crowell, K. G. , Goh, S. H. , and Hemmingsen, S. M. (2004) CpnDB: A chaperonin sequence database. *Genome Res* 14:1669-1675. www.genome.org

Hincha, D. K. , and Hagemann, M. (2004) Stabilization of model membranes during drying by compatible solutes involved in the stress tolerance of plants and microorganisms. *Biochem J* 383: 277-283.

Hincha, D. K. , Heber, U. , and Schmitt, J. M. (1985) Antibodies against individual thylakoid membrane proteins as molecular probes to study chemical and mechanical freezing damage in vitro. *Biochim Biophys Acta* 809: 337-344.

Hirani, T. A. , Suzuki, I. , Murata, N. , Hayashi, H. , and Eaton-Rye, J. J. (2001) Characterization of a two-component signal transduction system involved in the induction of alkaline phosphatase under phosphate-limiting conditions in *Synechocystis* sp. PCC 6803. *Plant Mol Biol* 45:133-144.

Hirotsu, S. , Abe, Y. , Okada, K. , Nagahara, N. , Høi, H. , Nishino, T. , and Hakoshima, T. (1999) Crystal structure of a multifunctional 2-Cys peroxiredoxin heme-binding protein 23 kDa/proKferation-associated gene product. *Proc Natl Acad Sci USA* 96:12333-12338.

Hisabori, T. , Hara, S. , Fujii, T. , Yamazaki, D. , Hosoya-Matsuda, N. , and Motohashi, K. (2005) Thioredoxin affinity chromatography: a useful method for further understanding the thioredoxin network. *J Exp Bot* 56:1463-1468.

Hishiya, S. , Hatakeyama, W. , Mizota, Y. , Hosoya-Matsuda, N. , Motohashi, K. , Ikeuchi, M. , and Hisabori, T. (2008) Binary reducing equivalents using NADPH: Thioredoxin reductase and ferredoxin-thioredoxin reductase in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *Plant Cell Physiol* 49:11-18.

Hochman A. , and Shemesh A. (1987) Purification and characterization of a catalase-peroxidase from the photosynthetic bacterium *Rhodospseudomonas capsulata*. *J Biol Chem* 262: 6871-6876.

Hoekstra, F. A. , Crowe, J. H. , Crowe, L. M. , van Roekel, T. , and Vermeer, E. (1992) Do phospholipids and sucrose determine membrane phase transitions in dehydrating pollen species? *Plant Cell Environ* 15: 601-606.

Holmgren, A. (1976) Hydrogen donor system for *Escherichia coli* ribonucleoside diphosphate reductase dependent upon glutathione. *Proc Natl Acad Sci USA* 73: 2275-2279.

Holmgren, A. (1989) Thioredoxin and glutaredoxin systems. *Biol Chem* 264:13963-13966.

Holmgren, A. , and Aslund, F. (1995) Glutaredoxin. *Methods Enzymol* 252:283-292.

Hondorp, E. R. , and Matthews, R. G. (2004) Oxidative stress inactivates cobalamin-independent methionine synthase (MetE) in *Escherichia coli*. *PLoS Biol* 2:1738-1753.

Hong, S.-K. , Cha, M.-K. , and Kim, I.-H. (2008) A glutaredoxin-fused holo peroxidase acts as an important player in hydrogen peroxide detoxification in late-phased growth of *Anabaena* sp. PCC7120. *Arch Biochem Biophys* 475: 42-49.

Hong, S. W. , and Vierling, E. (2000) Mutants of *Arabidopsis thaliana* defective in the acquisition of tolerance to high temperature stress. *Proc Natl Acad Sci USA* 97: 4392-4397.

Hongthong, A. , Sirijantarut, M. , Yutthanasirikul, R. , Senachak, J. , Kurdrir, P. , Chaevadhanarak, S. , and Tanticharoen, M. (2009) Sub-cellular proteomic characterization of the high-temperature stress response of the cyanobacterium *Spirulina platensis*. *Proteome Sci* 7: 33. doi:10.1186/1477-5966-7-33

Horiuchi, M. , Nakamura, K. , Koima, K. , Nishiyama, Y. , Hatakeyama, W. , Hisabori, T. , and Hihara, Y. (2010) The PedR transcriptional regulator interacts with thioredoxin to connect photosynthesis with gene expression in cyanobacteria. *Biochem J* 431:135-140.

Horlacher, R. , and Boss, W. (1997) Characterization of TreR., the major regulator of the *Escherichia coli* trehalose system. *J Biol Chem* 272:13026-13032.

Horváth, I. , Glatz, A. , Varvasovszki, V. , Torok, Z. , Páll, T. , Balogh, G. , Kovács, E. , Nádasdi, L. , Benko, S. , Joó, F. , and Vigh, L. (1998) Membrane physical state controls the signaling mechanism of the heat shock response in *Synechocystis* PCC 6803: Identification of Hsp17 as a "fluidity gene". *Proc Natl Acad Sci USA* 95: 3513-3518.

Hoskins, J. R. , Pak, M. , Maurizi, M. R. , and Wickner, S. (1998) The role of ClpA chaperone in proteolysis by ClpAP. *Proc Natl Acad Sci USA* 95:12135-12140.

Hosoya-Matsuda, N. , Motohashi, K. , Yoshimura, H. , Nozaki, A. , Inoue, K. , Ohmori M. , and Hisabori, T. (2005) Anti-oxidative stress system in cyanobacteria. Significance of type II peroxiredoxin and the role of 1-Cys peroxiredoxin in *Synechocystis* sp. strain PCC 6803. *J Biol Chem* 280: 840-846.

Hossain, M. M. , and Nakamoto, H. (2002) HtpG plays a role in cold acclimation in cyanobacteria. *Curr Microbiol* 44: 291-296.

Hossain, M. M. , and Nakamoto, H. (2003) Role for the cyanobacterial HtpG in protection from oxidative stress. *Curr Microbiol* 46: 70-76.

Hottiger, T. , De Virgilio, C. , Halí, N. M. , Boiler, T. , and Wiemken, A. (1994) The role of trehalose synthesis for the acquisition of thermotolerance in yeast. II. Physiological concentrations of trehalose increase the thermal stability of proteins in vitro. *Eur J Biochem* 219:187-193.

Hounsa, C. G. , Brandt, E.V. , Thevelein, J. , Hohmann, S. , and Prior, B. A. (1998) Role of trehalose in survival of *Saccharomyces cerevisiae* under osmotic stress. *Microbiology* 144: 671-680

Huang, E. , Fulda, S. , Hagemann, M. , and Norling, B. (2006) Proteomic screening of salt-stress induced changes in plasma membranes of *Synechocystis* sp. strain PCC 6803. *Proteomics* 6: 910-920.

Huang, L. , McCluskey M. P. , Ni, H. , and LaRossa, R. A. (2002) Global gene expression profiles of the cyanobacterium *Synechocystis* sp. strain PCC 6803 in response to irradiation with UV-B and white light. *J Bacteriol* 184: 6845-6858.

Huang, Z. B. , Liu, Y. D. , Paulsen, B. S. , and Klaveness, D. (1998) Studies on polysaccharides from three edible species of *Nostoc* (Cyanobacteria) with different colony morphologies: Comparison of monosaccharide compositions and viscosities of polysaccharides from field colonies and suspension cultures. *J Phycol* 34: 962-968.

Huckauf, J. , Nomura, C. , Forchhammer, K. , and Hagemann, M. (2000) Stress responses of *Synechocystis* sp. strain PCC 6803 mutants impaired in genes encoding putative alternative sigma factors. *Microbiology* 146:2877-2889.

Huesgen, P. E. , Scholz, P. , and Adamska, I. (2007) The serine protease HhoA from *Synechocystis* sp. strain PCC 6803: Substrate specificity and formation of a hexameric complex are regulated by the PDZ domain. *J Bacteriol* 189: 6611-6618.

Huesgen, P. E. , Schuhmann, H. , and Adamska, I. (2005) The family of Deg proteases in cyanobacteria and chloroplasts of higher plants. *Physiol Plant* 123: 413-420.

Huesgen, P. R. , Schuman, H. , and Adamska, I. (2009) Deg/HtrA proteases as components of a network for photosystem II quality control in chloroplasts and cyanobacteria. *Res Microbiol* 160: 726-732. doi:10.1016/j.resmic.2009.08.005

Huflejt, M. , Tremolieres, A. , Pineau, B. , Lang, J. , Hatheway, J. , and Packer, L. (1990) Changes in membrane lipid composition during *Synechococcus* 6311 growth. *Plant Physiol* 94:1512-1521.

Huner, N. P. A. , Maxwell, D. P. , Gray G. R. , Savitch, L. V. , Krol, M. , Ivanov, A. G. , and Falk, S. (1996) Sensing environmental temperature change through imbalances between energy supply and energy consumption: Redox state of photosystem II. *Physiol Plant* 98: 358-364.

Hwang, B. J. , Park, W. J. , Chung, C. H. , and Goldberg, A. L. (1987) *Escherichia coli* contains a soluble ATP-dependent protease (Ti) distinct from protease La. *Proc Natl Acad Sci USA* 84: 5550-5554.

Ihalainen, J. A. , D'Haene, S. , Yermenko, N. , van Roon, H. , Arteni, A. A. , Boekema, E. J. , van Grondelle, R. , Matthijs, H. C. , and Dekker, J. P. (2005) Aggregates of the chlorophyll-binding protein IsiA (CP43') dissipate energy in cyanobacteria. *Biochemistry* 44:10846-10853.

Imley, J. A. (2003) Pathways of oxidative damage. *Annu Rev Microbiol* 57: 395-418.

Inagaki, N. , Maitra, R. , Satoh, K. , and Pakrasi, H. B. (2001a) Amino acid residues that are critical for in vivo catalytic activity of CtpA, the carboxy-terminal processing protease for the D1 protein of photosystem II. *J Biol Chem* 276: 30099-30105.

Inagaki, N. , Yamamoto, Y. , and Satoh, K. (2001b) A sequential two-step proteolytic process in the carboxyl-terminal truncation of precursor D1 protein in *Synechocystis* sp. PCC 6803. *FEBS Lett* 509:197-201.

Incharoensakdi, A. , and Kum-Arb, U. (1998) Betaine aldehyde dehydrogenase from a halotolerant cyanobacterium *Aphanotece halophytica*: Purification, properties and regulation by salinity *J Sci Soc Thailand* 24:234-240.

Incharoensakdi, A. , Takabe, T. , and Akazawa, T. (1986) Effect of betaine on enzyme activity and subunit interaction of ribulose 1,5-bisphosphate carboxylase/oxygenase from *Aphanotece halophytica*. *Plant Physiol* 81:1044-1049.

Ishizaki-Nishizawa, O. , Fujii, T. , Azuma, M. , Sekiguchi, K. , Murata, N. , Ohtani, T. , and Toguri, T. (1996) Low-temperature resistance of higher plants is significantly enhanced by a nonspecific cyanobacterial desaturase. *Nat Biotechnol* 14: 1003-1006.

Ivncch, A. , Jakopitsch, C. , Auer, M. , Un, S. , and Obinger, C. (2003) Protein-based radicals in catalase-peroxidase of *Synechocystis* sp. PCC 6803. A multifrequency EPR investigation of wild-type and variants on the environment of heme active site. *J Am Chem Soc* 125:14093-14102.

Ivleva, N. , Sidoruk, K. , Pakrasi, H. B. , Shestakov, S.V. (2002) Study of functional roles of Ctp-family proteins in the cyanobacterium *Synechocystis* 6803. *Microbiology* 71: 509-513.

Jacquot, J. P. , Lancelin, J. M. , and Meyer, Y. (1997) Thioredoxins: Structure and function in plant cells. *New Phytol* 136: 543-570.

Jger, K. , and Potts, M. (1988) Distinct fractions of genomic DNA from cyanobacterium *Nostoc commune* that differ in the degree of methylation. *Gene* 74:197-201.

Jaki, B. , Heilmann, J. , and Sticher, O. (2000) New antibacterial metabolites from the cyanobacterium *Nostoc commune* (EAWAG 122b). *J Nat Prod* 63:1283-1285.

Jakopitsch, C. , Auer, M. , Regelsberger, G. , Jantschko, W. , Furtmller, P. G. , Rker, F. , and Obinger, C. (2003a) Distal site aspartate is essential in the catalase-peroxidase. *Biochemistry* 42: 5292-5300.

Jakopitsch, C. , Auer, M. , Regelsberger, G. , Jantschko, W. , Furtmller, P. G. , Rcker, R. , and Obinger, C. (2003b) The catalytic role of the distal site asparagine-histidine couple in catalase-peroxidases. *Eur J Biochem* 270:1006-1013.

Jakopitsch, C. , Auer, M. , Ivncch, A. , Rcker, F. , Furtmller, P. G. , and Obinger, C. (2003c) Total conversion of bifunctional catalase-peroxidase (KatG) to monofunctional peroxidase by exchange of a conserved distal side tyrosine. *J Biol Chem* 278: 20185-20191.

Jakopitsch, C. , Ivncch, A. , Schmuckenschlager, R. , Wanasinghe, A. , Polti, G. , Furtmller, P. G. , Rcker, R. , and Obinger, C. (2004) Influence of the unusual covalent adduct on the kinetics and formation of radical intermediates in *Synechocystis* catalase-peroxidase: A stopped-flow and EPR characterization of the Met275, Tyr241, and Arg431 variants. *J Biol Chem* 279: 46082-46095.

Jakopitsch, C. , Kolarich, D. , Petutschnig, G. , Furtmller, P. G. , and Obinger, C. (2003d) Distal side tryptophan, tyrosine and methionine in catalase-peroxidases are covalently linked in solution. *FEBS Lett* 552:135-140.

Jakopitsch, C. , Regelsberger, G. , Furtmller, P. G. , Rker, R. , Peschek, G. A. , and Obinger, C. (2001) Catalase-peroxidase from *Synechocystis* is capable of chlorination and bromination reactions. *Biochem Biophys Res Commun* 28: 682-687.

Jakopitsch, C. , Rker, R. , Regelsberger, G. , Dokal, R. , Peschek, G. A. , and Obinger, C. (1999) Catalase-peroxidase from the cyanobacterium *Synechocystis* PCC 6803: Cloning, overexpression in *Escherichia coli*, and kinetic characterization. *Biol Chem* 380:1087-1096.

Jakopitsch, C. , Vlasits, J. , Wiseman, B. , Loewen, P. C. , and Obinger, C. (2007) Redox intermediates in the catalase cycle of catalase-peroxidases from *Synechocystis* sp. PCC 6803, *Burkholderia pseudomallei* and *Mycobacterium tuberculosis*. *Biochemistry* 46:1183-1193.

Jakopitsch, C. , Wanasinghe, A. , Jantschko, W. , Furtmller, P. G. , and Obinger, C. (2005) Kinetics of interconversion of ferrous enzymes, compound II and compound III, wild-type *Synechocystis* catalase-peroxidase and Y249F. Proposal for the catalytic mechanism. *J Biol Chem* 280: 9037-9042.

Jansen, T. , Kidron, H. , Taipaleenmaki, H. , Salminen, T. , and Maenpaa, P. (2005) Transcriptional profiles and structural models of the *Synechocystis* sp. PCC 6803 Deg proteases. *Photosynth Res* 84: 57-63.

Jansch, E.R. , and Maclean, F. I. (1973) The effect of cold shock on the blue-green alga *Anacystis nidulans*. *Can J Microbiol* 19: 381-387.

Jarnagin, R. C. , and Wang, J. H. (1958) Investigation of the catalytic mechanism of catalase and other ferric compounds with doubly ¹⁸O-labeled hydrogen peroxide. *J Am Chem Soc* 80: 786-787.

Jeanjean, R. , Matthijs, H. C. P. , Onana, B. , Havaux, M. , and Joset, F. (1993) Exposure of the cyanobacterium *Synechocystis* PCC 6803 to salt stress induces concerted changes in respiration and photosynthesis. *Plant Cell Physiol* 34:1073-1079.

Jeanjean, R. , Zuther, E. , Yeremenko, N. , Havaux, M. , Matthijs, H. C. , and Hagemann, M. (2003) A photosystem 1 psaFJ-nuR mutant of the cyanobacterium *Synechocystis* PCC 6803 expresses the isiAB operon under iron replete conditions. *FEBS Lett* 549: 52-56.

Jentsch, S. (1996) When proteins receive deadly messages at birth. *Science* 271: 955-956.

Jiang, W. , Hou, Y. , and Inouye, M. (1997) CspA., the major cold-shock protein of *Escherichia coli*, is an RNA chaperone. *J Biol Chem* 272:196-202.

Jones, P. G. , and Inouye, M. (1994) The cold-shock response-a hot topic. *Mol Microbiol* 11: 811-818.

Jones, P. G. , Cashel, M. , Glaser, G. , and Neidhardt, F. C. (1992) Function of a relaxed-like state following temperature downshifts in *Escherichia coli*. *J Bacteriol* 174: 3909-3914.

Jones, P. G. , Mitta, M. , Kim, Y. , Jiang, W. , and Inouye, M. (1996) Cold shock induces a major ribosomal-associated protein that unwinds double-stranded RNA in *Escherichia coli*. *Proc Natl Acad Sci USA* 93: 76-80.

Joset, F. , Jeanjean, R. , and Hagemann, M. (1996) Dynamics of the response of cyanobacteria to salt stress: Deciphering the molecular events. *Physiol Plant* 96: 738-744.

Kaku, N. , Hibino, T. , Tanaka, Y. , Ishikawa, H. , Araki, E. , Takabe, T. , and Takabe, T. (2000) Effects of overexpression of *Escherichia coli* katE and bet genes on the tolerance for salt stress in a freshwater cyanobacterium *Synechococcus* sp. PCC 7942. *Plant Sci* 159:281-288.

Kaneko, T. , Sato, S. , Kotani, H. , Tanaka, A. , Asamizu, E. , Nakamura, Y. , Miyajima, N. , Hirose, M. , Sugita, M. , Sasamoto, S. , Kimura, T. , Hosouchi, T. , Matsuno, A. , Muraki, A. , Nakazaki, N. , Naruo, K. , Okumura, S. , Shimpo, S. , Takeuchi, C. , Wada, T. , Watanabe, A. , Yamada, M. , Yasuda, M. , and Tabata, S. (1996) Sequence analysis of the genome of the unicellular cyanobacterium *Synechocystis* sp. strain PCC6803. II. Sequence determination of the entire genome and assignment of potential protein-coding regions. *DNA Res* 3:109-136.

Kanesaki, Y. , Suzuki, I. , Allakhverdiev, S. I. , Mikami, K. , and Murata, N. (2002) Salt stress and hyperosmotic stress regulate the expression of different sets of genes in *Synechocystis* sp. strain PCC 6803. *Biochem Biophys Res Commun* 290: 339-348.

Kanesaki, Y. , Yamamoto, H. , Paithoonrangasiri, K. , Shoumskaya, M. , Suzuki, I. , Hayashi, H. , and Murata, N. (2007) Histidine kinases play important roles in the perception and signal transduction of hydrogen peroxide in the cyanobacterium *Synechocystis* sp. PCC 6803. *Plant J* 49:313-324.

Kappell, A. D. , and van Waasbergen, L. G. (2007) The response regulator RpaB binds the high light regulatory 1 sequence upstream of the high-light-inducible hliB gene from the cyanobacterium *Synechocystis* PCC 6803. *Arch Microbiol* 187: 337-342.

Karata, K. , Inagawa, T. , Wilkinson, A. J. , Tatsuta, T. , and Ogura, T. (1999) Dissecting the role of a conserved motif (the second region of homologue) in the AAA family of ATPases. Site directed mutagenesis of the ATP-dependent peptidase FtsH. *J Biol Chem* 274:26225-26232.

Karlson, D. , and Imai, R. (2003) Conservation of cold shock domain protein family in plants. *Plant Physiol* 131:12-15.

Karradt, A. , Sobanski, J. , Mattow, J. , Lockau, W. , and Baier, K. (2008) NblA., a key protein of phycobilisome degradation, interacts with ClpC., aHSP100 chaperone partner of a cyanobacterial Clp protease. *J Biol Chem* 283: 32394-32403.

Katano, Y. , Nimura-Matsune, K. , and Yoshikawa, H. (2006) Involvement of DnaK3, one of the three DnaK proteins of cyanobacterium *Synechococcus* sp. PCC 7942, in translational process on the surface of thylakoid membrane. *Biosci Biotechnol Biochem* 70:1592-1598.

Katayama-Fujimura, Y. S. , Gottesman, S. , and Maurizi, M. R. (1987) A multiple-component, ATP-dependent protease from *Escherichia coli*. *J Biol Chem* 262:4477-4485.

Kato, S. , Ueno, T. , Fukuzumi, S. , and Watanabe, Y. (2004) Catalase reaction by myoglobin mutants and native catalase: mechanistic investigation by kinetic isotope effect. *J Biol Chem* 279: 52376-52381.

Katoh, H. , Asthana, R. K. , and Ohmori, M. (2004) Gene expression in the cyanobacterium *Anabaena* sp. PCC 7120 under desiccation. *Microb Ecol* 47:164-174.

Kedar, L. , Kashman, Y. , and Oren, A. (2002) Mycosporine-2-glycine is the major mycosporine-like amino acid in a unicellular cyanobacterium (*Euhalothece* sp.) isolated from a gypsum crust in a hypersaline salt pond. *FEMS Microbiol Lett* 208: 233-237.

Keiler, K. C. , Waller, P. R. , and Sauer, R. T. (1996) Role of a peptide tagging system in degradation of proteins synthesized from damaged messenger RNA. *Science* 271: 990—993.

Kenny A. J. (1999) Nomenclature and Classes of Peptidases. In: Sterchi, E. E. , and Stocker, W. (Eds.) *Proteolytic Enzymes. Tools and Targets*, Springer Verlag, Heidelberg, Germany pp 1-8.

Keren, N. , Aurora, R. , and Pakrasi, H. B. (2004) Critical roles of bacterioferritins in iron storage and proliferation of cyanobacteria. *Plant Physiol* 135:1666-1673.

Kessel, M. , Maurizi, M. R. , Kim, B. , Kocsis, E. , Trus, B. L. , Singh, S. K. , and Steven, A. C. (1995) Homology in structural organization between *E. coli* ClpAP protease and the eukaryotic 26S proteasome. *J Mol Biol* 250: 587-594.

Khamutov, G. , Fry I. V. , Huflejt, M. E. , and Packer, L. (1990) Membrane lipid composition, fluidity, and surface charge changes in response to growth of the freshwater cyanobacterium *Synechococcus* 6311 under high salinity *Arch Biochem Biophys* 277: 263-267.

Kieselbach, T. , and Funk, C. (2003) The family of Deg/HtrA proteases: From *Escherichia coli* to Arabidopsis. *Physiol Plant* 119: 337-346.

Kihara, A. , Akiyama, Y. , and Ito, K. (1995) FtsH is required for proteolytic elimination of uncomplexed forms of SecY., an essential protein translocase subunit. *Proc Natl Acad Sci USA* 92:4532-4536.

Kim, K. I. , Park, S. C. , Kang, S. H. , Cheong, G. W. , and Chung, C. H. (1999) Selective degradation of unfolded proteins by the self-compartmentalizing Htr A peptidase, a periplasmic heat stress protein in *Escherichia coli*. *J Mol Biol* 294:1363-1374.

Kim, S. W. , Choi, I. R. , Kim, S. N. , Kim, Y. R. , Pyo, S. N. , and Rhee, D. K. (1998). Molecular cloning, expression, and characterization of dnaK in *Streptococcus pneumoniae*. *FEMS Microbiol Lett* 161: 217-224.

Kis, M. , Zsiros, O. , Farkas, T. , Wada, R. , Nagy E. , and Gombos, Z. (1998) Light-induced expression of fatty acid desaturase genes. *Proc Natl Acad Sci USA* 95: 4209-4210.

Kiseleva, L. L. , Serebriiskaya, T. S. , Horváth, I. , Vigh, L. , Lyukevich, A. A. , and Losa, D. A. (2000) Expression of the gene for the A9 acyl-lipid desaturase in the thermophilic cyanobacterium. *J Mol Microbiol Biotechnol* 2: 331-338.

Kláhn, S. , and Hagemann, M. (2011) Compatible solute biosynthesis in cyanobacteria. *Environ Microbiol* 13: 551-562. doi: 10.1111/j.1462-2920.2

Klughammer, B. , Baier, M. , and Dietz, K. J. (1998) Inactivation by gene disruption of 2-cysteine-peroxiredoxin in *Synechocystis* sp. PCC 6803 leads to increased stress sensitivity. *Physiol Plant* 104: 699-706.

Knowles, E.I. , and Castenholz, R. W. (2008) Effect of exogenous extracellular polysaccharides on the desiccation and freezing tolerance of rock-inhabiting phototrophic microorganisms. *FEMS Microbiol Ecol* 66: 261-270.

Kobayashi, M. , Ishizuka, T. , Katayama, M. , Kanehisa, M. , Bhattacharyya-Pakrasi, M. , Pakrasi, H. B. , and Ikeuchi, M. (2004) Response to oxidative stress involves a novel peroxiredoxin gene in the unicellular cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Cell Physiol* 45: 290-299.

Kojima, K. , and Nakamoto, H. (2002) Specific binding of a protein to a novel DNA element in the cyanobacterial small heat-shock protein gene. *Biochem Biophys Res Commun* 151: 616-624.

Kojima, K. , and Nakamoto, R. (2005) Post-transcriptional control of the hspA heat-shock induction. *Biochem Biophys Res Commun* 331: 583-588.

Kojima, K. , Suzuki-Maenaka, T. , Kikuchi, T. , and Nakamoto, R. (2006) Roles of isiABC operon in protection from oxidative and heat stresses. *Physiol Plant* 128: 507-519.

Kolman, M. A. , Torres, L. L. , Martin, M. L. , and Salerno, G. L. (2012) Sucrose synthase in unicellular cyanobacteria and its relationship with salt and hypoxic stress. *Planta*: 235: 955-964. doi:10.1007/s00425-011-1542-5

Komenda, I. , Barker, M. , Kuvikova, S. , de Vries, R. , Mullineaux, C. W. , Tich, M. , and Nixon, P. J. (2006) The FtsH protease slr0228 is important for quality control of photosystem II in the thylakoid membr  n   of *Synechocystis* sp PCC 6803. *J Biol Chem* 281:1145-1151.

Komenda, I. , Knoppov  , I. , Krynick  , V. , Nixon, P. I. , and Tichy, M. (2010) Role of FtsH2 in the repair of photosystem II in mutants of the cyanobacterium *Synechocystis* PCC 6803 with impaired assembly or stability of the CaMn4 cluster. *Biochim Biophys Acta* 1797: 566-575. doi:10.1016/j.bbabi.2010.02.006

Kou  il, R. , Arteni, A. A. , Lax, I. , Yeremenko, N. , D'Haene, S. , Rogner, M. , Matthijs, H. C. , Dekker, J. P. , and Boekema, E. J. (2005) Structure and functional role of supercomplexes of IsiA and Photosystem I in cyanobacterial photosynthesis. *FEBS Lett* 579: 3253-3257.

Krojer, T. , Garrido-Franco, M. , Huber, R. , Ehrmann, M. , and Clausen, T. (2002) Crystal structure of DegP (HtrA) reveals a new protease-chaperone machine. *Nature (London)* 416: 455-459.

Kujat, S. L. , and Owtrim, G.W. (2000) Redox-regulated RNAhelicase expression. *Plant Physiol* 124: 703-713.

Kulkarni, R. D. , and Golden, S. S. (1997) mRNA stability is regulated by a coding-region element and the unique 59-untranslated leader sequences of the three *Synechococcus* psbA transcripts. *Mol Microbiol* 24:1131-1142.

Kulkarni, R. D. , Schaefer, M. R. , and Golden, S. S. (1992) Transcriptional and posttranscriptional components of psbA response to high light intensity in *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 174: 3775-3781.

Kuo, C. R. , Mashino, T. , and Fridovich, I. (1987) a,P-Dihydroxyisovalerate dehydratase superoxide. A sensitive enzyme. *J Biol Chem* 262: 4724-4727

Lacerda, C. M. R. , Choe, L. H. , and Reardon, K. F. (2007) Metaproteomics analysis of a bacterial community response to cadmium exposure. *J Proteome Res* 6:1145-1152.

Lamark, T. , Kaasen, I. , Eshoo, M. W. , Falkenberg, P. , McDougall, J. , and Strom, A. R. (1991) DNA sequence and analysis of five bet genes encoding the osmoregulatory choline-glycine betaine pathway of *Escherichia coli*. *Mol Microbiol* 5:1049-1064.

Lara, C. , Rodr  guez, R. , and Guerrero, M. G. (1993). Sodium-dependent nitrate transport and energetics of cyanobacteria. *J Phycol* 29: 389-395.

Laloknam, S. , Tanaka, K. , Buaboocha, T. , Waditee, R. , Incharoensakdi, A. , Hibino, T. , Tanaka, Y. , and Takabe, T. (2006) Halotolerant cyanobacterium *Aphanothece halophytica* contains a betaine transporter active at alkaline pH and high salinity. *Appl Environ Microbiol* 72: 6018-6026.

Landfald, B. , and Strom, A. R. (1986) Choline-glycine betaine pathway confers a high level of osmotic tolerance in *Escherichia coli*. *J Bacteriol* 165: 849-855.

La Teana, A. , Brandi, A. , Falconi, M. , Spurion, R. , Pon, C. , and Gualerzi, C. O. (1991) Identification of a cold shock transcriptional enhancer of the *Escherichia coli* gene encoding nucleoid protein H-NS. *Proc Natl Acad Sci USA* 88:10907-10911.

Latifi, A. , Jeanjean, R. , Lemeille, S. , Havaux, M. , and Zhang, C.-C. (2005) Iron starvation leads to oxidative stress in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 187: 6596-6598.

Latifi, A. , Ruiz, M. , and Zhang, C.-C. (2009) Oxidative stress in cyanobacteria. *FEMS Microbiol Rev* 33: 258-278.

Latifi, A. , Ruiz, M. , Jeanjean, R. , and Zhang, C. C. (2007) PrxQ-A., a member of the peroxiredoxin Q family, plays a major role in defense against oxidative stress in the cyanobacterium *Anabaena* sp. strain PCC7120. *Free Radic Biol Med* 42:424-431.

Laudenbach, D. E. , and Straus, N. A. (1988) Characterization of a cyanobacterial iron stress-induced gene similar to psbC. *J Bacteriol* 170: 5018-5026.

Laudenbach, D. E. , Reih, M. E. , and Straus, N. A. (1988) Isolation, sequence analysis, and transcriptional studies of the flavodoxin gene from *Anacystis nidulans* R2. *J Bacteriol* 170: 258-265.

Laudenbach, D. E. , Triek, C. G. , and Straus, N. A. (1989) Cloning and characterization of an *Anacystis nidulans* R2 superoxide dismutase gene. *Mol Gen Genet* 216: 455-461.

Lee, B. H. , Hibino, T. , Jo, J. , Viale, A. M. , and Takabe, T. (1997) Isolation and characterization of a dnaK genomic locus in a halotolerant cyanobacterium *Aphanothece halophytica*. *Plant Mol Biol* 35: 763-775.

Lehel, C. , Los, D. , Wada, H. , Gyorgyei, J. , Horv  th, I. , Kov  cs, E. , Murata, N. , and Vigh, L. (1993) A second GroEL-like gene organized in a groEL-operon is present in the genome of *Synechocystis* sp. PCC 6803. *J Biol Chem* 268:1799-1804.

Lehel, C. , Wada, H. , Torok, Z. , Gombos, Z. , Murata, N. , and Vigh, L. (1992) Heat shock protein synthesis of the cyanobacterium *Synechocystis* PCC 6803. Purification of the GroEL-related chaperonin. *Plant Mol Biol* 18: 327-336.

LeKveit, M. J. , and Kawula, T. H. (1995) Hsc66, an Hsp70 homolog in *Escherichia coli*, is induced by cold shock but not by heat shock. *J Bacteriol* 177: 4900-4907.

Lensch, M. , Herrmann, R. G. , and Sokolenko, A. (2001) Identification and characterization of SppA., a novel light-inducible chloroplast peptidase complex associated with thylakoid membranes. *J Biol Chem* 276:33645-33651.

Leonhardt, K. , and Straus, N. A. (1992) An iron stress operon involved in photosynthetic electron transport in the marine cyanobacterium *Synechococcus* sp. PCC 7002. *J Gen Microbiol* 138:1613-1621.

Leonhardt, K. , and Straus, N. A. (1994) Photosystem II genes isiA., psbDI and psbC in *Anabaena* sp. PCC 7120: Cloning, sequencing and the transcriptional regulation in iron-stressed and iron-repleted cells. *Plant Mol Biol* 24: 63-73.

Leonhardt, S. A. , Fearon, K. , Danese, P. N. , and Mason, T. L. (1993) Hsp78 encodes a yeast mitochondrial heat shock protein in the Clp family of ATP-dependent proteases. *Mol Cell Biol* 13: 6304-6313.

Leske, S. B. , Israeli, E. , Lighthart, B. , Crowe, J. H. , and Crowe, L. M. (1995) Trehalose and sucrose protect both membranes and proteins in intact bacteria during drying. *Appl Environ Microbiol* 61:3592-3597.

LesKe, S. B. , Teter, S. A. , Crowe, L. M. , and Crowe, J. H. (1994) Trehalose lowers membrán phase transitions in dry yeast cells. *Biochim Biophys Acta* 1192: 7-13.

Lewin A. , Moore G.R. , Le Brun N.E. (2005) Formation of protein-coated iron minerals. *Dalton Trans* 3597-3610.

Li, H. , and Sherman, L. A. (2000) A redox-responsive regulátor of photosynthesis gene expression in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 182: 4268-4277.

Li, H. , Singh, A. K. , McIntyre, L. M. , and Sherman, L. A. (2004) Differential gene expression in response to hydrogen peroxide and the putative PerR regulon of *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 186: 3331-3345.

Li, M. , Huang, W. , Yang, G. , Liu, X. , and Wu, Q. (2005) Expression and oxidative stress tolerance studies of glutaredoxin from cyanobacterium *Synechocystis* sp. PCC 6803 in *Escherichia coli*. *Protein Expr Purif*: 85-91.

Li, M. , Yang, Q. , Zhang, L. , Li, H. , Cui, Y. , and Wu, Q. (2007) Identification of novel targets of cyanobacterial glutaredoxin. *Arch Biochem Biophys* 458: 220-228.

Li, T. , Huang, X. , Zhou, R. , Liu, Y. , Li, B. , Nomura, C. , and Zhao, J. (2002) Differential expression and localization of Mn and Fe superoxide dismutases in the heterocystous cyanobacterium *Anabaena* sp. strain PCC 7120. *J Bacteriol* 184: 5096-5103.

Li, T. , Yang, H. M. , Cui, S. X. , Suzuki, I. , Zhang, L. R. , Li, L. , Bo, T. , Wang, J. , Murata, N. , and Huang, F. (2012) Proteomic study of the impact of Hik33 mutation in *Synechocystis* sp. PCC 6803 under normal and salt stress conditions. *J Proteome Res* 11: 502-514.

Liang, C. , Zhang, X. , Chi, X. , Guan, X. , Li, Y. , Qin, S. , and bo Shao, H. (2011) Serine/Threonine protein kinase SpkG is a candidate for high salt resistance in the unicellular cyanobacterium *Synechocystis* sp. PCC 6803. *PLoS ONE* 6: e18718. doi:10.1371/journal.pone.0018718

Liao, D. I. , Qian, J. , Chisholm, D. A. , Jordán, D. B. , and Diner, B. A. (2000) Crystal structures of the photosystem II D1 C-terminal processing protease. *Nat Struct Biol* 7: 749-753.

Liberek, K. , Marszałek, J. , Ang, D. , Georgopoulos, C. , and Zylicz, M. (1991). *Escherichia coli* DnaJ and GrpE heat shock proteins jointly stimulate ATPase activity of DnaK. *Proc Natl Acad Sci USA* 88: 2874-2878.

Lin, Y. , Hirai, M. , Kashino, Y. , Koike, H. , Tuzi, S. , and Satoh, K. (2004) Tolerance to freezing stress in cyanobacteria, *Nostoc commune* and some cyanobacteria with varying tolerances to drying stress. *Polar Biosci* 17: 56-68.

Lindahl, M. , and Florencio, F. J. (2003) Thioredoxin-linked processes in cyanobacteria are as numerous as in chloroplasts, but targets are different. *Proc Natl Acad Sci USA* 100:16107-16112.

Linder, E. , Lásko, P. F. , Ashburner, M. , Leroy P. , Nielson, P. J. , Nishi, K. , Schnier, J. , and Slonimski, P. P. (1989) Birth of the D - E - A - D box. *Nature (London)* 337:121-122.

Lipinska, B. , Zylicz, M. , and Georgopoulos, C. (1990) The HtrA (DegP) protein, essential for *Escherichia coli* survival at high temperatures, is an endopeptidase. *J Bacteriol* 172:1791-1797.

Liu, Y. , Yu, L. , Ke, W. , Gao, X. , and Qiu, B. (2010) Photosynthetic recovery of *Nostoc flagelliforme* upon rehydration after 2 years and 8 years dry storage. *Phycologia* 49:429-437. doi: 10.2216/09-011

Loprasert, S. , Negoro, S. , and Okada, H. (1989) Cloning, nucleotide sequence, and expression in *Escherichia coli* of the *Bacillus stearotherophilus* peroxidase gene (perA). *J Bacteriol* 171: 4871-4875.

Los, D. A. (2004) The effect of low-temperature-induced DNA supercoiling on the expression of the desaturase genes in *Synechocystis*. *Cell Mol Biol* 50: 605-612.

Los, D. A. , and Murata, N. (1994) The low-temperature-induced accumulation of the desA transcript in *Synechocystis* PCC6803 is a result of both activation of transcription and maintenance of RNA stability. *Russian J Plant Physiol* 41:146-151.

Los, D. A. , and Murata, N. (1998) Structure and expression of fatty acid desaturases. *Biochim Biophys Acta* 394: 3-15.

Los, D. A. , and Murata, N. (1999) Response to cold-shock in cyanobacteria. *J Mol Microbiol Biotechnol* 1: 221-230.

Los, D. A. , and Murata, N. (2000) Regulation of enzymatic activity and gene expression by membrán fluidity. *Science's Signal Transduction Knowledge Environment* (http://www.ske.org/cgi/content/full/OC_sigtrans;2000/62/pel).

Los, D. A. , and Murata, N. (2004) Membrán fluidity and its roles in the perception of environment signals. *Biochim Biophys Acta* 1666:142-157.

Los, D. A. , and Zinchenko, V. V. (2000) Regulatóry role of membrán fluidity in gene expression. In: Wada, H. , and Murata, N. . (Eds) *Lipids in Photosynthesis. Structure, Function and Genetics*. Springer Science + Business Media, B.V. Berlin, Germany pp. 329-348.

Los, D. A. , Horváth, I. , Vigh, L. , and Murata, N. (1993) The temperature-dependent expression of the desaturase gene desA in *Synechocystis* PCC 6803. *FEBS Lett* 318: 57-60.

Los, D. A. , Ray M. K. , and Murata, N. (1997) Differences in the control of the temperature-dependent expression of four genes for desaturases in *Synechocystis* sp. PCC 6803. *Mol Microbiol* 25:1167-1176.

Los, D. A. , Suzuki, I. , Zinchenko, V. V. , and Murata, N. (2008) Stress responses in *Synechocystis*: regulated genes and regulatóry systems. In: Herrero, A. , and Flores, E. . (Eds) *The Cyanobacteria: Molecular Biology, Genomics and Evolution*, Caister Academic Press: Norfolk, UK. pp. 117-157.

Los, D. A. , Zorina, A. , Sinetova, M. , Kryazhov, S. , Mironov, K. , and Zinchenko, V. (2010) Stress sensors and signal transducers in cyanobacteria. *Sensors* 10: 2386-2415. doi:10.3390/s100302386

Lovelock, J. E. (1953) Het (SicJ) mechanism of the protective action of glycerol against haemolysis by freezing and thawing. *Biochim Biophys Acta* 11: 28-36.

Lu, C. , and Zhang, J. (2000) Role of Kgt in response of PSU photochemistry to salt stress in the cyanobacterium *Spirulina platensis*. *J Exp Bot* 51: 911-917.

Macedo, M. F. , Miller, A. Z. , Dionísio, A. , and Saiz-Jimenez, C. (2009) Biodiversity of cyanobacteria and green algae on monuments in the Mediterranean Basin: An overview. *Microbiology* 155:3476-3490.

Mackay M. A. , Horton, R. S. , and Borowitzka, L. J. (1984) Organic osmoregulatory solutes in cyanobacteria. *J Gen Microbiol* 130:2177-2191.

Maestri, O. , and Joset, F. (2000) Regulation by external pH and stationary growth phase of the acetolactate synthase from *Synechocystis* PCC 6803. *Mol Microbiol* 37: 828-838.

Makarova, K. S. , Omelchenko, M. V. , Gaidamakova, E. K. , Matrosova, V. Y. , Vasilenko, A. , Zhai, M. , Lapidus, A. , Copeland, A. , Kim, E. , Land, M. , Mavromatis, K. , Pitluck, S. , Richardson, P. M. , Detter, C. , Brettin, T. , Saunders, E. , Lai, B. , Ravel, B. , Kemner, K. M. , Wolf, Y. I. , Sorokin, A. , Gerasimova, A. V. , Gelfand, M. S. , Fredrickson, J. K. , Koonin, E. V. , and Daly, M. J. (2007) *Deinococcus geothermalis*: the pool of extrémé radiation resistance genes shrinks. *PLoS ONE* 2: e955. doi:10.1371/journal.pone.0000955

Mann, N. H. , Novac, N. , Mullineaux, C. W. , Newman, J. , Bailey, S. , and Robinson, C. (2000) Involvement of an FtsH homologue in the assembly of functional photosystem I in the cyanobacterium *Synechocystis* sp. PCC 6803. *Febs* 479: 72-77.

Marcinkeviciene, J. A. , Magliozzo, R. S. , and Blanchard, J. S. (1995) Purification and characterization of the *Mycobacterium smegmatis* catalase-peroxidase involved in isoniazid activation. *J Biol Chem* 270: 22290-22295.

Marcus, R. , Moberly, L. , and Latshaw, S. P. (1988) Comparative amino acid sequence of fructose-1,6-bisphosphatase: Identification of a region unique to the light-regulated chloroplast enzyme. *Proe Nati Acad Sci USA* 85: 5379-5383.

Marin, K. , Huckauf, J. , Fulda, S. , and Hagemann, M. (2002) Salt-dependent expression of glucosylglycerol-phosphate synthase, involved in osmolyte synthesis in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 184:2870-2877.

Marin, K. , Kanesaki, Y. , Los, D. A. , Murata, N. , Suzuki, I. , and Hagemann, M. (2004) Gene expression profiling reflects physiological processes in salt acclimation of *Synechocystis* sp. strain PCC 6803. *Plant Physiol* 136:3290-3300.

Marin, K. , Strinberg, M. , Eisenhut, M. , Krämer, R. , and Hagemann, M. (2006) Osmotic stress in *Synechocystis* sp. PCC 6803: Low tolerance towards nonionic osmotic stress results from lacking activation of glucosylglycerol accumulation. *Microbiology* 152: 2023-2030.

Marin, K. , Suzuki, I. , Yamaguchi, K. , Ribbeck, K. , Yamamoto, H. , Kanesaki, Y. , Hagemann, M. , and Murata, N. (2003) Identification of histidine kinases that act as sensors in the perception of salt stress in *Synechocystis* sp. strain PCC 6803. *Proe Nati Acad Sci USA* 100: 9061-9066.

Martin, J. L. (1995) Thioredoxin-a fold for all reasons. *Structure* 3:245-250.

Martinez, M. R. (1988) *Nostoc commune* Vauch., a nitrogen-fixing blue-green alga, as source of food in the Philippines. *Phil Agric* 71: 295-307.

Martinez, M. R. , and Querijero, N. M. B. (1986) Macrocolony formation in the nitrogen-fixing blue-green alga, *Nostoc commune* Vauch. *Phil Agric* 69: 547-565.

Maruyama, K. , Sato, N. , and Ohta. (1999) Conservation of structure and cold-regulation of RNA-binding proteins in cyanobacteria: Probable convergent evolution with eukaryotic glycine-rich RNA-binding proteins. *Nucleic Acids Res* 27:2029-2036.

Mary, I. , Tu, C. J. , Grossman, A. , and Vault, D. (2004) Effects of high light on transcripts of stress-associated genes for the cyanobacteria *Synechocystis* sp. PCC 6803 and *Prochlorococcus* MED4 and MIT9313. *Microbiology* 150:1271-1281.

Masip, L. , Veeravalli, K. , and Georgiou, G. (2006) The many faces of glutathione in bacteria. *Antiox Redox Signál* 8: 753-762.

Maurizi, M. R. (1991) ATP-promoted interaction between ClpA and ClpP protease in activation of Clp protease from *Escherichia coli*. *Biochem Soc Trans* 19: 719-723.

McCarty J. S. , and Walker, G. C. (1991) DnaK as thermometer: Threonine-199 is site of autophosphorylation and is critical for ATPase activity *Proe Nati Acad Sci USA* 88: 9513-9517.

McCarty, J. S. , and Walker, G. C. (1994) DnaK mutants defective in ATPase activity are defective in negative regulation of the heat shock response: Expression of mutant DnaK proteins results in filamentation. *J Bacteriol* 176: 764—780.

McCord, J. M. , and Fridovich, I. (1969) Superoxide dismutase an enzymic function for erythrocuprein (hemocuprein). *J Biol Chem* 244: 6049-6055.

Meyer, Y. , Reichheld, J. P. , and Vignols, F. (2005) Thioredoxins in *Arabidopsis* and other plants. *Photosynth Res* 86: 419-433.

Meyer, Y. , Buchanan, B. B. , Vignols, R. , Reichheld, J. P. (2009) Thioredoxins and Glutaredoxins: Unifying elements in redox biology. *Annu Rev Genetics* 43:335-367.

Mikami, K. , Kanesaki, Y. , Suzuki, I. , and Murata, N. (2002) The histidine kinase Hik33 perceives osmotic stress and low-temperature stress in *Synechocystis* sp. PCC 6803. *Mol Microbiol* 46: 905-915.

Mikkat, S. , Hagemann, M. , and Schoor, A. (1996) Active transport of glucosylglycerol is involved in salt adaptation of the cyanobacterium *Synechocystis* sp. strain PCC 6803. *Microbiology* 141: 1725-1732.

Miller, A-F. (2004) Superoxide dismutases active sites that save, but a protein hat kills. *Curr Opin Chem Biol* 8:162-168.

Miller, E. W. , Tullythan, O. , Isacoff, E. Y. , and Chang, C. (2007) Molecular imaging of hydrogen peroxide produced for cell signaling. *Nat Chemical Biol* 3:263-267. doi:10.1038/nchembio871

Miranda-Vizuete, A. , Rodriguez-Ariza, A. , Toribio, E. , Holmgren, A. , Lopez-Barea, J. , and Pueyo, C. (1996) The levels of ribonucleotide reductase, thioredoxin, glutaredoxin 1, and GSH are balanced in *Escherichia coli* K12. *J Biol Chem* 271: 19099-19103.

Missiakas, D. , Schwager, R. , Betton, J.-M. , Georgopoulos, C. , and Raina, S. (1996) Isolation and characterization of HslV HslU (ClpQ ClpY) proteins involved in overall proteolysis of misfolded proteins in *E. coli*. *Embo J* 15: 6899-6909.

Miyake, C. , Michihata, R. , and Asada, K. (1991) Scavenging of hydrogen peroxide in prokaryotic and eukaryotic algae: acquisition of ascorbate peroxidase during the evolution of cyanobacteria. *Plant Cell Physiol* 32: 33-43.

Mizuno, T. , Kaneko, T. , and Tabata, S. (1996) Compilation of all genes encoding bacterial two-component signal transducers in the genome of the cyanobacterium *Synechocystis* sp. strain PCC 6803. *DNA Res* 3: A07-A1A.

Mogk, A. , Deuerling, E. , Vorderwulbecke, S. , Vierling, E. , and Bukau, B. (2003). Small heat shock proteins, ClpB and the DnaK system form a functional triade in reversing protein aggregation. *Mol Microbiol* 50: 585-595.

Mogk, A. , Tomoyasu, T. , Goloubinoff, R. , Rüdiger, S. , Roder, D. , Langen, H. , and Bukau, B. (1999) Identification of hermolabile *Escherichia coli* proteins: prevention and reversion of aggregation by DnaK and ClpB. *Embo J* 18: 6934-6949.

Mohamed, A. , and Jansson, C. (1989) Influence of light on accumulation of photosynthesis-specific transcripts in the cyanobacterium *Synechocystis*. *Plant Mol Biol* 13: 693-700.

Mohamed, A. , Eriksson, J. , Osiewacz, H. , and Jansson, C. (1993) Differential expression of the *psbA* genes in the cyanobacterium *Synechocystis*. *Mol Gen Genet* 238:161-168.

Mohamed, A. , and Jansson, C. (1989) Influence of light on accumulation of photosynthesis-specific transcripts in the cyanobacterium *Synechocystis*. *Plant Mol Biol* 13: 693-700.

Mongkolsuk, S. , and Hermann, J. D. (2002) Regulation of inducible peroxide stress responses. *Mol Microbiol* 45: 9-15.

Møi, S. , Castoreno, A. , Mulligan, M. E. , and Lammers, P. J. (2003) Nitrogen status modulates the expression of RNA-binding proteins in cyanobacteria. *FEMS Microbiol Lett* 227: 203-210.

Morsay R. M. , Kuzuha, S. , Takáni, Y. , and Sakamoto, T. (2008) Novel thermostable glycosidases in the extracellular matrix of the terrestrial cyanobacterium *Nostoc commune*. *J Gen Appl Microbiol* 54: 243-252.

Motohashi, K. , Watanabe, Y. , Yohda, M. , and Yoshida, M. (1999) Heat-inactivated proteins are rescued by the DnaJ-GrpE set and ClpB chaperones. *Proe Nati Acad Sci USA* 96: 7184-7189.

Müller, D. R. , Vincent, W. R. , Bonilla, S. , and Laurion, I. (2005) Extremotrophs, extremophiles and broadband pigment strategies in a high arctic ice shelf system. *FEMS Microb Ecol* 53: 73-87.

Muller, E. D. G. , and Buchanan, B. B. (1989) Thioredoxin is essential for photosynthetic growth. *J Biol Chem* 264:4008-4014.

Mulligan, M. E. , Jackman, D. M. , and Murphy S. T. (1994) Heterocyst forming filamentous cyanobacteria encode proteins that resemble eukaryotic RNA-binding proteins of the RNP family *J Mol Biol* 235:1162-1170.

Murata, N. (1989) Low-temperature effects on cyanobacterial membranes. *J Bioenerg Biomembr* 21: 61-75.

Murata, N. , and Los, D. A. (1997) Membrane fluidity and temperature perception. *Plant Physiol* 115: 875-879.

Murata, N. , and Los, D. A. (2006) Histidine kinase Hik33 is an important participant in cold signal transduction in cyanobacteria. *Physiol Plant* 126:17-27.

Murata, N. , and Nishida, I. (1987) Lipids of blue-green algae (cyanobacteria). In: Stumpf, R. K. . (Ed.) *The Biochemistry of Plants*, Vol. 9. Academic Press, San Diego, CA, USA. pp. 315-347.

Murata, N. , and Siegenthaler, P. A. (2004) Lipids in photosynthesis: An overview. In: Wada, H., and Murata, N. (Eds) *Lipids in Photosynthesis. Structure, Function and Genetics*. Springer Science + Business Media, B.V Berlin, Germany pp. 1-20.

Murata, N. , and Suzuki, I. (2006) Exploitation of genomic sequences in a systematic analysis to access how cyanobacteria sense environmental stress. *J Exp Bot* 57: 235-247.

Murata, N. , and Wada, H. (1995) Acyl-Kpid desaturases and their importance in the tolerance and acclimatization to cold of cyanobacteria. *Biochem J* 308:1-8.

Murata, N. , Ishizaki-Nishizawa, O. , Higashi, H. , Hayashi, H. , Tasaka, Y. , and Nishida, I. (1992a) Genetically engineered alteration in the chilling sensitivity of plants. *Nature (London)* 356: 710-713.

Murata, N. , Ono, T. , and Sato, N. (1979) Lipid phase of membrane and chilling injury in the blue-green alga *Anacystis nidulans*. In: Lyons, J. M. , Graham, D. , and Raison, J. K. . (Eds.) *Low Temperature Stress in Crop Plants*. Academic Press, New York, NY., USA. pp. 337-345.

Murata, N. , Wada, H. , and Gombos, Z. (1992b) Modes of fatty-acid desaturation in cyanobacteria. *Plant Cell Physiol* 33: 933-941.

Mustardy L. , Los, D. A. , Gombos, Z. , and Murata, N. (1996) Immunocytochemical localization of acyl-lipid desaturases in cyanobacterial cells: Evidence that both thylakoid membranes and cytoplasmic membranes are sites of lipid desaturation. *Proc Natl Acad Sci USA* 93:10524-10527.

Mutsaers, M. , Ishikawa, T. , Takeda, T. , and Shigeoka, S. (1996) The catalase-peroxidase of *Synechococcus* PCC 7942: purification, nucleotide sequence analysis and expression in *Escherichia coli*. *Biochem J* 316: 251-257.

Nakamoto, H. , and Honma, D. (2006) Interaction of small heat-shock protein with light harvesting cyanobacterial phycocyanins under stress conditions. *FEBS Lett* 580: 3029-3034.

Nakamoto, H. , and Vigh, L. (2007) The small heat shock proteins and their clients. *Cell Mol Life Sci* 64:294—306.

Nakamoto, H. , Suzuki, N. , and Roy S. K. (2000) Constitutive expression of a small heat-shock protein confers cellular thermotolerance and thermal properties to the photosynthetic apparatus in cyanobacteria. *FEBS Lett* 483:169-174.

Nakamoto, H. , Suzuki, N. , and Kojima, K. (2003) Targeted inactivation of the *hrcA* repressor gene in cyanobacteria. *FEBS Lett* 549: 57-62.

Nakamoto, H. , Tanaka, N. , and Ishikawa, N. (2001) A novel heat shock protein plays an important role in thermal stress management in cyanobacteria. *J Biol Chem* 276: 25088-25095.

Nakamura, K. , and Hihara, Y. (2006) Photon flux density-dependent gene expression in *Synechocystis* sp. PCC 6803 is regulated by a small, redox-responsive, LuxR-type regulator. *J Biol Chem* 281: 36758-36766.

Nakamura, T. , Naito, K. , Yokota, N. , Sugita, C. , and Sugita, M. (2007) A cyanobacterial non-coding RNA., *Yfr1*, is required for growth under multiple stress conditions. *Plant Cell Physiol* 48:1309-1318.

Nakamura, Y. , Kaneko, T. , Hirose, M. , Miyajima, N. , and Tabata, S. (1998) CyanoBase, a www database containing the complete nucleotide sequence of the genome of *Synechocystis* sp. strain PCC 6803. *Nucleic Acids Res* 26: 63-67.

Narberhaus, F. (1999) Negative regulation of bacterial heat shock genes. *Mol Microbiol* 31:1-8.

Navarro, R. , and Florencio, F. J. (1996) The cyanobacterial thioredoxin gene is required for both photoautotrophic and heterotrophic growth. *Plant Physiol* 111: 1067-1075.

Newkirk, K. , Feng, W. , Jiang, W. , Tejero, R. , Emerson, S. D. , Inouye, M. , and Montekone, G. T. (1994) Solution NMR structure of the major cold shock protein (CspA) from *Escherichia coli*: Identification of a binding epitope for DNA. *Proc Natl Acad Sci USA* 91: 5114-5118.

Newton, G. L. , Arnold, K. , Price, M. S. , Sherrill, C. , Delcardayre, S. B. , Aharonowitz, Y. , Cohen, G. , Davies, I., Fahey R. C., and Davis, C. (1996) Distribution of thiols in microorganisms: mycothiol is a major thiol in most actinomycetes. *J Bacteriol* 178:1990-1995.

Nienow, J. A. , and Friedmann, E. I. (1993) Terrestrial lithophilic (rock) communities. In: Friedmann, E. I. , and Thistle, A. B. (Eds.) *Antarctic Microbiology*. John Wiley & Sons, Inc., New York, NY., USA. pp. 343-412.

Nierhaus, K. H. , and Wilson, D. N. . (Eds.) (2004) *Protein Synthesis and Ribosome Structure. Translating the Genome*. Wiley-VCH Verlag GmbH & Co. KGaA., Weinheim, Germany

Nimura, K. , Takahashi, H. , and Yoshikawa, H. (2001) Characterization of the *dnaK* multigene family in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 183:1320-1326.

Nimura, K. , Yoshikawa, H. , and Takahashi, H. (1994a) Identification of *dnaK* multigene family in *Synechococcus* sp. PCC 7942. *Biochem Biophys Res Commun* 201:466-471.

Nimura, K. , Yoshikawa, H. , and Takahashi, H. (1994b) Sequence analysis of the third *dnaK* homolog gene in *Synechococcus* sp. PCC 7942. *Biochem Biophys Res Commun* 201: 848-854.

Nimura, K. , Yoshikawa, H. , and Takahashi, H. (1996) DnaK3, one of the three DnaK proteins of cyanobacterium *Synechococcus* sp. PCC 7942, is quantitatively detected in the thylakoid membrane. *Biochem Biophys Res Commun* 229: 334-340.

Nishiyama, Y. , and Hisabori, T. (2009) Physiological impact of thioredoxin- and glutaredoxin-mediated redox regulation in cyanobacteria. *Adv Bot Res* 52:187-205.

Nishiyama, Y. , Hayashi, H. , Watanabe, T. and Murata, N. (1994) Photosynthetic oxygen evolution is stabilized by cytochrome C550 against heat inactivation in *Synechococcus* sp. PCC 7002. *Plant Physiol* 105:1313-1317.

Nishiyama, Y. , Kovács, E. , Lee, C. B. , Hayashi, H. , Watanabe, T. , and Murata, N. (1993) Photosynthetic adaptation to high temperature associated with thylakoid membranes of *Synechococcus* PCC 7002. *Plant Cell Physiol* 34: 337-343.

Nishiyama, Y. , Los, D.A. , Hayashi, H. , and Murata, N. (1997) Thermal protection of the oxygen-evolving machinery by PsbU., an extrinsic protein of photosystem II in *Synechococcus* sp. PCC 7002. *Plant Physiol* 115:1473-1480.

Nishiyama, Y. , Los, D. A. , and Murata, N. (1999) PsbU., a protein associated with photosystem II., is required for the acquisition of cellular thermotolerance in *Synechococcus* sp. PCC 7002. *Plant Physiol* 120: 301-308.

Nishiyama, Y. , Yamamoto, H. , Allakhverdiev, S. I. , Inaba, M. , Yokota, A. , and Murata, N. (2001) Oxidative stress inhibits the repair of photodamage to the photosynthetic machinery. *Embo J* 20: 5587-5594.

Nitta, K. , Suzuki, N. , Honma, D. , Kaneko, Y. , and Nakamoto, H. (2005) Ultrastructural stability under high temperature or intensive light stress conferred by a small heat shock protein in cyanobacteria. *FEBS Lett* 579:1235-1242.

Nixon, P. I. , Barker, M. , Boehm, M. , de Vries, R. , and Komenda, J. (2005) FtsH-mediated repair of the photosystem II complex in response to light stress. *J Exp Bot* 56: 357-363.

Nixon, P. I. , Trošt, J. T. , and Diner, B. A. (1992) Role of carboxyl-terminus of polypeptide D1 in the assembly of a functional water-oxidizing manganese cluster in photosystem II of the cyanobacterium *Synechocystis* sp. PCC 6803: Assembly requires a free carboxyl group at C-terminal position 344. *Biochemistry* 31:10859-10871.

Nocker, A. , Hausherr, T. , Balsiger, S. , Krstulovic, N. P. , Hennecke, H. , and Narberhaus, F. (2001) AmRNA-based thermosensor controls expression of rhizobial heat shock genes. *Nucleic Acids Res* 29: 4800-4807.

Nomura, M. , Hibino, T. , Takabe, T. , Sugiyama, T. , Yokota, A. , Miyake, H. , and Takabe, T. (1998) Transgenically produced glycine betaine protects ribulose 1,5-biphosphate carboxylase/oxygenase from inactivation in *Synechococcus* sp. PCC 7942 under salt stress. *Plant Cell Physiol* 39:425-432.

Nomura, M. , Ishitani, M. , Takabe, T. , Rai, A. K. , and Takabe, T. (1995) *Synechococcus* sp. PCC 7942 transformed with *Escherichia coli* bet genes produces glycine betaine from choline and acquires resistance to salt stress. *Plant Physiol* 107: 703-708.

Nyossola, A. , Kerovuo, I. , Kaukinen, P. , Von Weymar, N. , and Reinikainen, T. (2000) Extrême halophiles synthesize betaine from glycine by methylation. *J Biol Chem* 275: 22196-22201.

Obinger, C. , Regelsberger, G. , Strasser, G. , Burner, U. , and Peschek, G. A. (1997) Purification and characterization of a homodimeric catalase-peroxidase from the cyanobacterium *Anacystis nidulans*. *Biochem Biophys Res Commun* 235: 545-552.

Ohad, I. , Nivo, R. , Brumfeld, V. , Reich, Z. , Tsur, T. , Yair, M. , and Kaplan, A. (2005) Inactivation of photosynthetic electron flow during desiccation of desert biological sand crusts and *Microcoleus* sp. enriched isolates. *Photochem Photobiol Sci* 4: 977-982.

Ohad, I. , Raanan, H. , Keren, N. , Tchernov, D. , and Kaplan, A. (2010) Light-induced changes within photosystem II protects *Microcoleus* sp. biological desert sand crusts against excess light. *PLoS ONE* 5: e10000. doi:10.1371/journal.pone.0011000

Ohnishi, N. , and Murata, N. (2006) Glycine betaine counteracts the inhibitory effects of salt stress on the degradation and synthesis of D1 protein during photoinhibition in *Synechococcus* sp. PCC 7942. *Plant Physiol* 141: 758-765.

Okada, S. , Kanematsu, S. , and Asada, K. (1979) Intracellular distribution of manganese and ferric superoxide dismutases in blue-green algae. *FEBS Lett.* 103:106-110.

Okamoto, S. , Yamanishi, Y. , Ehira, S. , Kawashima, S. , Tonomura, K. , and Kanehisa, M. (2007) Prediction of nitrogen metabolism-related genes in *Anabaena* by kernel-based network analysis. *Proteomics* 7: 900-909. doi: 10.1002/pmic.200600862

Oldham, M. L. , Brash, A. R. , Newcomer, M. E. (2005) The structure of coral allene oxide synthase reveals a catalase adapted for metabolism of a fatty acid hydroperoxide. *Proc Natl Acad Sci USA* 102: 297-302.

Olsson-Francis, K. , de la Torre, R. , and Cockell, C. S. (2010) Isolation of novel extrême tolerant cyanobacteria from a rock-dwelling microbial community by using exposure to low earth orbit. *Appl Environ Microbiol* 76:2115-2121.

Omata, T. , and Murata, N. (1983) Isolation and characterization of the cytoplasmic membranes from the blue-green alga (cyanobacterium) *Anacystis nidulans*. *Plant Cell Physiol* 24:1101-1112.

Ono, T.-A. , and Murata, N. (1981a) Chilling susceptibility of the blue-green alga, *Anacystis nidulans* I. Effect of growth temperature. *Plant Physiol* 67:176-181.

Ono, T.-A. , and Murata, N. (1981b) Chilling susceptibility of the blue-green alga, *Anacystis nidulans* II. Stimulation of the passive permeability of cytoplasmic membranes at chilling temperatures. *Plant Physiol* 67:182-187.

Ono, T.-A. , and Murata, N. (1982) Chilling susceptibility of the blue-green alga, *Anacystis nidulans* III. Lipid phase of cytoplasmic membranes. *Plant Physiol* 69:125-129.

Oren, A. (1977) Mycosporine-like amino acids as osmotic solutes in a community of halophilic cyanobacteria. *Geomicrobiol J* 14: 231-240.

Oren, A. , and Gunde-Cimerman, N. (2007) Mycosporines and mycosporine-like amino acids: UV protectants or multipurpose secondary metabolites. *FEMS Microbiol Lett* 269:1-10.

Owtrim, G. W. (2006) RNA helicases and abiotic stress. *Nucleic Acids Res* 34: 3220-3230.

Padán, E. , and Schuldiner, S. (1994) Molecular physiology of the Na⁺/H⁺ antiporter in *Escherichia coli*. *J Exp Biol* 196: 443-456.

Padán, E. , and Schuldiner, S. (1996) Bacterial Na⁺/H⁺ antiporters-molecular biology, biochemistry and physiology. In: Konings, W. N. , Kaback, H. R. , and Lolkema, J. S. . (Eds) *Handbook of Biological Physics*, Vol 2. Elsevier Science Publishers, Amsterdam, The Netherlands. pp. 501-531.

Padán, E. , Venturi, M. , Gerchman, Y. , and Dover, N. (2001) Na⁺/H⁺ antiporters. *Biochim Biophys Acta* 1505:144-157.

Paithoonrangasrid, K. , Shoumskaya, M. A. , Kanesaki, Y. , Satoh, S. , Tabata, S. , Los, D. A. , Zinchenko, V. V. , Hayashi, H. , Tanticharoen, M. , Suzuki, I. , and Murata, N. (2004) Five histidine kinases perceive osmotic stress and regulate distinct sets of genes in *Synechocystis*. *J Biol Chem* 279: 53078-53086.

Pandhal, J. , Wright, P. C. , and Biggs, C. A. (2008) Proteomics with a pinch of salt: A cyanobacterial perspective. *Salin systems* 4:1 doi:10.1186/1746-1448-4-1

Panichkin, V. B. , Glazer, V. M. , Zinchenko, V. V. , Sokolenko, A. , Herrmann, R. G. , and Shestakov, S. V. (2001) clpPI gene encoding peptidase in cyanobacteria *Synechocystis* sp. PCC 6803 controls the sensitivity of cells to photoinhibition. *Izv Akad Nauk SSSR Ser Biol* 3: 312-317.

Panoff, J. M. , Priem, B. , Morvan, H. , and Joset, F. (1988) Sulphated exopolysaccharides produced by two unicellular strains of cyanobacteria, *Synechocystis* PCC 6803 and 6714. *Arch Microbiol* 150: 558-563.

Park, S. K. , Kim, K. I. , Woo, K. M. , Seol, J. R. , Tanaka, K. , Ichihara, A. , Ha, D. B. , and Chung, C. H. (1993) Site-directed mutagenesis of the dual translational initiation sites of the clpB gene in *Escherichia coli* and characterization of its gene product. *J Biol Chem* 268: 20170-20174.

Park, Y.-L. , Sandstrom, S. , Gustafsson, P. , and Óquist, G. (1999) Expression of the isiA gene is essential for the survival of the cyanobacterium *Synechococcus* sp. PCC 7942 by protecting photosystem II from excess light under iron limitation. *Mol Microbiol* 32:123-129.

Parsell, D. A. , and Lindquist, S. (1993) The function of heat-shock proteins in stress tolerance: Degradation and reactivation of damaged proteins. *Annu Rev Genet* 27: 437-496.

Pascual, M. B. , Mata-Cabana, A. , Florencio, E. , Lindahl, M. , and Cejudo, F. J. (2010) Overoxidation of 2-Cys peroxiredoxin in prokaryotes: Cyanobacterial 2-Cys peroxiredoxins sensitive to oxidative stress. *J Biol Chem* 285:34485-34492.

Pascual, M. B. , Mata-Cabana, A. , Florencio, F. , Lindahl, M. , and Cejudo, F. J. (2011) A comparative analysis of NADPH thioredoxin reductase C-2-Cys peroxiredoxin system from plants and cyanobacteria. *Plant Physiol* 155:1806-1816.

Passardi, F. , Zamocky, M. , Favet, J. , Jakopitsch, C. , Penel, C. , Obinger, C. , and Dunand, C. (2007) Phylogenetic distribution of catalase-peroxidases: are here patches of order in chaos? *Gene* 397:101-113.

Patterson-Fortin, L. M. , Colvin, K. R. , and Owtrim, G. W. (2006) A Lex-A-related protein regulates redox-sensitive expression of the cyanobacterial RNA helicase, CrhR. *Nucleic Acids Res* 34: 3446-3454.

Pause, A. , and Sonenberg, N. (1993) Helicases and RNA unwinding in translation. *Curr Opin Struct Biol* 3: 953-959.

Peat, A. , Powell, N. , and Potts, M. (1988) Ultrastructural analysis of the rehydration of desiccated *Nostoc commune* HUN (Cyanobacteria) with particular reference to the immunolabelling of NifH. *Protoplasma* 146: 72-80.

Pentecost, A. (1985) Relationships between light, temperature and photosynthesis in a temperate *Microcoleis* (cyanobacterium) mat. *Microbios* 43:141-148.

Pereira, S. , Zille, A. , Micheletti, E. , Moradas-Ferreira, P. , DePhilippis, R. , and Tamagnini, P. (2009) Complexity of cyanobacterial exopolysaccharides, composition, structures, inducing factors and putative genes involved in their biosynthesis and assembly *FEMS Microbiol Rev* 33: 917-941.

Perelman, A. , Uzan, A. , Hachou, D. , and Schwarz, R. (2003) Oxidative stress in *Synechococcus* sp. strain PCC 7942: various mechanisms for H₂O₂ detoxification with different physiological roles. *J Bacteriol* 185: 3654—3660.

Pérez-Ruiz, J. M. , Spinola, M. C. , Kirchsteiger, K. , Møeno, J. , Sahrawy M. , and Cejudo, F. J. (2006) Rice NTRC is a high-efficiency redox system for chloroplast protection against oxidative damage. *Plant Cell* 18:2356-2368.

Pérez-Pérez, M. E. , Florencio, F. J. , and Lindahl, M. (2006) Selecting thioredoxins for disulphide proteomics: target proteomes of three thioredoxins from the cyanobacterium *Synechocystis* sp. PCC 6803. *Proteomics* 6 (Suppl. 1): S186-S195.

Pérez-Pérez, M. E. , Mata-Cabana, A. , Sánchez-Riego, M. , Lindahl, M. , and Florencio, F. J. (2009) A comprehensive analysis of the peroxiredoxin reductase system in the cyanobacterium *Synechocystis* sp. strain PCC 6803 reveals that all five peroxiredoxins are thioredoxin dependent. *J Bacteriol* 191: 7477-7489.

Phadtare, S. (2004) Recent developments in bacterial cold-shock response. *Curr Issues Mol Biol* 6:125-136.

Phadtare, S. , and Severinov, K. (2010) RNA modeling and gene regulation by cold shock proteins. *RNA Biology* 7: 788-795. doi:10.4161/rna.7.6.13482

Piek, U. , Weiss, M. , Gounaris, K. , and Barber, J. (1987) The role of different thylakoid glycoproteins in the function of reconstituted chloroplast ATP synthase. *Biochim Biophys Acta* 891: 28-39.

Pócs, T. (2009) Cyanobacterial crust types, as strategies for survival in extreme habitats. *Acta Bot Hungarica* 51:147-178.

Pomati, F. , Burns, B. P. , and Neilan, B. A. (2004) Use of ion channel modulating agents to study cyanobacterial Na⁺-K⁺ fluxes. *Biol Proceed Online* 6:137-143. doi:10.1251/bpo82

Pomposiello, P. J. , and Dimple, B. (2001) Redox-operated genetic switches: the SoxR and OxyR transcription factors. *Trends Biotechnol.* 19:109-114.

Ponting, C. P. (1997) Evidence for PDZ domains in bacteria, yeast, and plants. *Protein Sci* 6: 464-468.

Portwich, A. , and Garcia-Pichel, F. (1999) Ultraviolet and osmotic stresses induce and regulate the synthesis of mycosporines in the cyanobacterium *Chlorogloeopsis* PCC 6912. *Arch Microbiol* 172:187-192.

Portwich, A. , and Garcia-Pichel, F. (2000) A novel prokaryotic UVB photoreceptor in the cyanobacterium *Chlorogloeopsis* PCC 6912. *Photochem Photobiol* 71: 493-498.

Poole, L. B. (2005) Bacterial defenses against oxidants: mechanistic features of cysteine-based peroxidases and their flavoprotein reductases. *Arch Biochem Biophys* 433: 240-254.

Porankiewicz, J. , and Clarke, A. K. (1997) Induction of the heat shock protein ClpB affects cold acclimation in the cyanobacterium *Synechococcus* sp. strain PCC 7942. *J Bacteriol* 179: 5111-5117.

Porankiewicz, J. , Wang, J. , and Clarke, A. K. (1999) New insights into the ATP-dependent Clp protease: *Escherichia coli* and beyond. *Mol Microbiol* 32: 449-458.

Porankiewicz, J. , Schelin, J. , and Clarke A. K. (1998) The ATP-dependent Clp peptidase is essential for acclimation to UV-B and low temperature in the cyanobacterium *Synechococcus*. *Mol Microbiol* 29: 275-283.

Porter, M. A. , Stringer, C. D. , and Hartman, F. C. (1988) Characterization of the regulatory thioredoxin site of phosphoribulokinase. *J Biol Chem* 263:123-129.

Potts, M. (1985) Protein synthesis and proteolysis in immobilized cells of the cyanobacterium *Nostoc muscorum* UTEX 584 exposed to matrix water stress. *J Bacteriol* 164:1025-1031.

Potts, M. (1994) Desiccation tolerance of prokaryotes. *Microbiol Rev* 58: 755-805.

Potts, M. (1996) The anhydrobiotic cyanobacterial cell. *Physiol Plant* 97: 788-794.

Potts, M. (1999) Mechanisms of desiccation tolerance in cyanobacteria. *Eur J Phycol* 34: 319-328.

Potts, M. (2000) *Nostoc*. In: Whitton B. A. , and Potts M. . (Eds.), *Ecology of Cyanobacteria: Their Diversity in Time and Space*. Kluwer Academic, Dordrecht, The Netherlands. pp. 465-504.

Potts, M. (2001) Desiccation tolerance: a simple process? *Trends Microbiol* 9: 553-559.

Potts, M. , and Bowman, M. A. (1985) Sensitivity of *Nostoc commune* UTEX 584 (cyanobacteria) to water stress. *Arch Microbiol* 141: 51-56.

Potts, M. , and Friedmann, E. I. (1981) Effects of water stress on cryptoendolithic cyanobacteria from hot desert rocks. *Arch Microbiol* 130:267-271.

Potts, M. , and Morrison, N. S. (1986) Shifts in the intracellular ATP pools of immobilized *Nostoc* cells (cyanobacteria) induced by water stress. *Plant Soil* 90:211-221.

Potts, M. , and Whitton, B. A. (1977). Nitrogen fixation by blue-green algal communities in the intertidal zone of the lagoon of Aldabra Atoll. *Oecologia (Berl.)* 27:275-283.

Potts, M. , and Whitton, B. A. (1980). Vegetation of the intertidal zone of the lagoon of Aldabra, with particular reference to the photosynthetic prokaryotic communities. *Proc R Soc B London* 208:13-55.

Potts, M. , Bowmann, M. A. , and Morrison, N. S. (1984) The matrix water potential (Ψ) in immobilized cultures of cyanobacteria. *FEMS Microbiol Lett* 24:193-196.

Potts, M. , Slaughter, S. M. , Hunneke, F-U. , Garst, J. R. , and Helm, R. F. (2005) Desiccation tolerance of prokaryotes: Application of principles to human cells. *Integr Camp Biol* 45: 800-809.

Prakash, J. S. S. , Krishna, P. S. , Sirisha, K. , Kaneshaki, Y. , Suzuki, I. , Shivaji, S. , and Murata, N. (2010) An RNA helicase, CrhR., regulates the low-temperature-inducible expression of heat-shock genes groES., groEL in *Synechocystis* sp. PCC 6803. *Microbiology* 156: 442-451.

Prakash, J.S.S. , Sinetova, M. , Zorina, A. , Kupriyanova, E. , Suzuki, I. , Murata, N. , and Los, D. A. (2009) DNA supercoiling regulates the stress-inducible expression of genes in the cyanobacterium *Synechocystis*. *Mol Biosyst* 5:1904-1912.

Priya, B. , Premanadh, J. , Dhanalakshmi, R. T. , Seethalakshmi, T. , Uma, L. , Prabakaran, D. , and Subramanian, G. (2007) Comparative analysis of cyanobacterial superoxide dismutases to discriminate canonical forms. *BMC Genomics* 8:435. doi:10.1186/1471-2164-8-435.

Priya, B. , Sivaprasanth, R. K. , Jensi, V. D. , Uma, L. , Subramanian, G. , and Prabakaran, D. (2010) Characterization of manganese superoxide dismutase from a marine cyanobacterium *Leptolyngbya valderiana* BDU 200041. *Salini Systems* 6.6. doi:10.1186/1746-1448-6-6.

Proctor, M. C. F. (2003) Comparative ecophysiological measurements on the Kght responses, water relations and desiccation tolerance of the filmy ferns *Hymenophyllum wilsonii* Hook and *H. tunbrigense* (L.) Smith. *Ann Bot* 91: 717-727.

Proteau, P. J. , Gerwick, W. H. , Garcia-Pichel, F. , and Castenholz, R. (1993) The structure of scytonemin, an ultraviolet sunscreen pigment from the sheaths of cyanobacteria. *Experientia* 49: 825-829.

Qiu, B. , and Price, N. M. (2009) Different physiological response of four marine *Synechococcus* strains (Cyanophyceae) to nickel starvation under iron replete and iron-deplete conditions. *J Phycol* 45:1062-1071.

Qiu, B. , Liu, J. , Liu, Z. , and Liu, S. (2002) Distribution and ecology of the edible cyanobacterium Ge-Xian-Mi (*Nostoc*) in rice fields of Hefeng County in China. *J Appl Phycol* 14: 423-429.

Rajaram, H. , and Apte, S. K. (2003) Heat-shock response and its contribution to thermotolerance of the nitrogen-fixing cyanobacterium *Anabaena* sp. strain L-31. *Arch Microbiol* 179:423-429.

Rajaram, H. , and Apte, S. K. (2008) Nitrogen status and heat-stress-dependent differential expression of the cpn60 chaperonin gene influences thermotolerance in the cyanobacterium *Anabaena*. *Microbiology* 154:317-325. doi: 10.1099/mic.0.2007/011064.0

Rajaram, H. , Ballal, A. D. , Apte, S. K. , Wiegert, T. , and Schumann, W. (2001) Cloning and characterization of the major groESL operon from a nitrogen-fixing cyanobacterium *Anabaena* sp. strain L-31. *Biochim Biophys Acta* 1519:143-146.

Rao, V. S. K. , Brand, J. J. , and Myers, J. (1977) Cold shock syndrome in *Anacystis nidulans*. *Plant Physiol* 59: 965-969.

Rawlings, N. D. , and Barrett, A. J. (1999) MEROPS: the peptide database. *Nucleic Acids Res.* 27:325-331.

Ray M. K. , Sitaramamma, T. , Ghandhi, S. , and Shivaji, S. (1994) Occurrence and expression of cspA., a cold shock gene, in Antarctic psychotrophic bacteria. *FEMS Microbiol Lett* 116: 55-60.

Reddy A. S. , Nuccio, M. L. , Gross, L. M. , and Thomas, T. L. (1993) Isolation of A6-desaturase gene from the cyanobacterium *Synechocystis* sp. strain PCC 6803 by gain-of-function expression in *Anabaena* sp. strain PCC7120. *Plant Mol Biol* 27: 283-300.

Reddy, B. M. , Apte, S. K. , and Thomas, J. (1989) Enhancement of cyanobacterial salt tolerance by combined nitrogen. *Plant Physiol* 89:204-210.

Reed, R. H. , and Stewart, W. D. P. (1985) Osmotic adjustment and organic solute accumulation in unicellular cyanobacteria from freshwater and marine habitats. *Mar Biol* 88:1-9.

Reed, R. R. , Borowitzka, L. J. , Mackay M. A. , Chudek, J. A. , Foster, R. , Warr, S. R.C. , Moore, D. J. , and Stewart W. D. P. (1986) Organic solute accumulation in osmotically stressed cyanobacteria. *FEMS Microbiol Rev* 39: 51-56.

Regelsberger, G. , Atzenhofer, W. , Rucker, E. , Peschek, G. A. , Jakopitsch, C. , Paumann, M. , Furtmüller, P. G. , and Obinger, C. (2002) Biochemical characterization of a membrani bound manganese-containing superoxide dismutase from the cyanobacterium *Anabaena* sp. PCC 7120. *J Biol Chem* 277: 43615-43622.

Regelsberger, G. , Laaha, U. , Dietmann, D. , Rucker, E. , Canini, A. , Grilli-Caiola, M. , Furtmüller, P. G. , Kakopitsch, C. , Peschek, G. A. , and Obinger, C. (2004) The iron superoxide dismutase from the filamentous cyanobacterium *Nostoc* PCC 7120. *J Biol Chem* 279:44384-44393.

Regelsberger, G. , Jakopitsch, C. , Rucker, E. , Krois, D. , Peschek, G.A. , and Obinger, C. (2000) Effect of distal cavity mutations on the formation of compound I in catalase-peroxidases. *J Biol Chem* 275: 22854-22861.

Regelsberger, G. , Jakopitsch, C. , Furtmüller, P. G. , Rucker, E. , Switala, J. , Loewen, P. C. , and Obinger, C. (2001) The role of distal tryptophan in the bifunctional activity of catalase-peroxidases. *Biochem Soc Trans* 29: 99-105.

Regelsberger, G. , Obinger, C. , Zoder, R. , Altmann, E. , and Peschek, G. A. (1999) Purification and characterization of a hydroperoxidase from the cyanobacterium *Synechocystis* PCC 6803: identification of its gene by peptide mass mapping using matrix assisted laser desorption ionization time-of-flight mass spectrometry *FEMS Microbiol Lett* 170:1-12.

Reyes, J. C. , and Florencio, F. J. (1995) Electron transport controls transcription of the glutamine synthetase gene (glnA) from the cyanobacterium *Synechocystis* sp. PCC 6803. *Plant Mol Biol* 27: 789-799.

Øezanka, T. , Vidin, I. , Go, J. V. , Dor, I. , and Dembitsky V. M. (2003) Polar lipids and fatty acids of three wild cyanobacterial strains of the genus *Chroococcidiopsis*. *Folia Microbiol* 48: 781-786.

Richards, A. B. , Krakowka, S. , Dexter, L. B. , Schmid, H. , Wolterbeek, A. P. M. , Waalkens-Berendsen, D. H. , Shigoyuki, A. , and Kurimoto, M. (2002) Trehalose: A review of properties, history of use and human tolerance, and results of multiple safety studies. *Food Chem Toxicol* 40: 871-898.

Ritchie, R. J. (1991) Membrane-potential and pH control in the cyanobacterium *Synechococcus* R-2 (*Anacystis nidulans*) PCC 7942. *J Plant Physiol* 137:409-418.

Ritchie, R. J. (1992) Sodium transport and the origin of the membrani potential in the cyanobacterium *Synechococcus* R-2 (*Anacystis nidulans*) PCC 7942. *J Plant Physiol* 139:320-330.

Ritchie, R. J. (1998) Bioenergetics of membrani transport in *Synechococcus* R-2 (*Anacystis nidulans*, *S. kopolensis*) PCC 7942. *Can J Bot* 76:1127-1145.

Richter, S. , Hagemann, M. , and Messer, W. (1998) Transcription analysis and mutation of a dnaA-like gene in *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 180: 4946-4949.

Ritossa, F. (1962) A new puffing pattern induced by heat shock and DNP in *Drosophila*. *Experientia* 18: 571-573.

Ritter, D. , and Yopp, J. H. (1993) Plasma membrani lipid composition of the halophilic cyanobacterium *Aphanothece halophytica*. *Arch Microbiol* 159:435-439.

Ritz, D. , and Beckwith, J. (2001) Roles of thiol-redox pathways in bacteria. *Annu Rev Microbiol* 55:21-48.

Rocak, S. , and Linder, P. (2004) DEAD-box proteins: the driving forces behind RNA metabolism. *Nat Rev Mol Cell Biol* 5: 232-241.

Rocap, G. , Larimer, F. W. , Lamerdin, J. , Malfatti, S. , Chain, P. , Ahlgren, N. A. , Arellano, A. , Coleman, M. , Hauser, L. , Hess, W. R. , Johnson, Z. I. , Land, M. , Lindell, D. , Post, A. F. , Regala, W. , Shah, W. M. , Shaw, S. L. , Steglich, C. , Sullivan, M. B. , Ting, C. S. , Tolonen, A. , Webb, E. A. , Zinser, E. R. , and Chisholm, S. W. (2003) Genome divergence in two *Prochlorococcus* ecotypes reflects oceanic niche differentiation. *Nature (London)* 424:1042-1047.

Rodriguez-Manzanique, M. T. , Ros Cabisco, E. , Sorribas, A. , and Herrero, E. (1999) Grx5 glutaredoxin plays a central role in protection against protein oxidative damage in *Saccharomyces cerevisiae*. *Mol Cell Biol* 19: 8180-8190.

Ross, C. , Santiago-Vázquez, L. , and Paul, V. (2006) Toxin release in response to oxidative stress and programmed cell death in the cyanobacterium *Microcystis aeruginosa*. *Aquat Toxicol* 78: 66-73.

Rowland, J. G. , Pang, X. , Suzuki, I. , Murata, N. , Simon, W. J. , and Slabas, A. R. (2010) Identification of components associated with thermal acclimation of photosystem II in *Synechocystis* sp. PCC 6803. *PLoS ONE* 5: e10511. doi:10.10371/journal.pone.0010511

Roy S. K. , and Nakamoto, H. (1998) Cloning, characterization, and transcriptional analysis of a gene encoding an α -crystallin-related, small heat shock protein from the thermophilic cyanobacterium *Synechococcus vulcanus*. *J Bacteriol* 180: 3997-4001.

Roy, S. K. , Hiyama, T. , and Nakamoto, H. (1999) Purification and characterization of the 16-kDa heat-shock-responsive protein from the thermophilic cyanobacterium *Synechococcus vulcanus*, which is an α -crystallin-related. *Eur J Biochem* 262: 406-416.

Rozema, J. , Björn, L. O. , Bornman, J. F. et al. (2002) The role of UV-B radiation in aquatic and terrestrial ecosystems- an experimental and functional analysis of the evolution of UV-absorbing compounds. *J Photochem Photobiol* 66:2-12.

Rupprecht, E. , Gathmann, S. , Fuhrmann, E. , and Schneider, D. (2007) Three different DnaK proteins are functionally expressed in the cyanobacterium *Synechocystis* sp. PCC 6803. *Microbiology* 153:1828-1841. doi:10.1099/mic0.2007/005876-0

Ryu, J.-Y. , Suh, K.-H. , Chung, Y.-H. , Park, Y.-M. , Chow, W. S. , and Park, Y.-H. (2003) Cytochrome c oxidase of the cyanobacterium *Synechocystis* sp. PCC 6803 protects photosynthesis from salt stress. *Mol cell* 16: 74-77.

Sabacka, M. , and Elster, J. (2006) Response of cyanobacteria and algae from Antarctic wetland habitats to freezing and desiccation stress. *Polar Biol* 30: 31-37.

Sakamoto, T. , and Bryant, D. A. (1997) Temperature-regulated mRNA accumulation and stabilization for fatty acid desaturase genes in the cyanobacterium *Synechococcus* sp. strain PCC 7002. *Mol Microbiol* 23:1281-1292.

Sakamoto, T. , and Bryant, D. A. (1998) Growth at low temperature causes nitrogen limitation in the cyanobacterium *Synechococcus* sp. PCC 7002. *Arch Microbiol* 169:10-19.

Sakamoto, T. , and Bryant, D. A. (1999) Nitrate transport and not photoinhibition limits growth of freshwater cyanobacterium *Synechococcus* species PCC 6301 at low temperature. *Plant Physiol* 119: 785-794.

Sakamoto, T. , Higashi, S. , Wada, H. , Murata, N. , and Bryant, D. A. (1997a) Low-temperature-induced desaturation of fatty acids and expression of desaturase genes in the cyanobacterium *Synechococcus* sp. PCC 7002. *FEMS Microbiol Lett* 152: 313-320.

Sakamoto, T. , Stirewalt, V. L. , and Bryant, D. A. (1997b) Two acyl-lipid A9 desaturase genes of the cyanobacterium *Synechococcus* sp. PCC 7002. In: Williams, J. P. , Khan, M. U. , and Lem, N. W. . (Eds.) *Physiology, Biochemistry, and Molecular Biology of Plant Lipids* Kluwer, Dordrecht, The Netherlands. pp. 380-381.

Sakamoto, T. , Wada, H. , Nishida, I. , Ohmori, M. , and Murata, N. (1994) A9 Acyl-lipid desaturases of cyanobacteria: Molecular cloning and substrate specificities in terms of fatty acids, sn-positions, and polar head groups. *J Biol Chem* 269: 25576-25580.

Sakamoto, T. , Yoshida, T. , Arima, H. , Hatanaka, Y. , Takán, Y. , and Tamaru, Y. (2009) Accumulation of trehalose in response to desiccation and salt stress in the terrestrial cyanobacterium *Nostoc commune*. *Phycological Res* 57: 66-73.

Sakthivel, K. , Watanabe, T. , and Nakamoto, H. (2009) A small heat-shock protein confers stress tolerance and stabilizes thylakoid membrane proteins in cyanobacteria under oxidative stress. *Arch Microbiol* 191: 319-328.

Salin, M. L. (1991). Chloroplast and mitochondrial mechanisms for protection against oxygen toxicity. *Free Rad Res Commun* 12-13: 851-858.

Sanchez, Y. , and Lindquist, S. L. (1990) HSP104 required for induced thermotolerance. *Science* 248:1112-1115.

Sandstrom, S. , Park, Y.-L. , Öquist, G. , and Gustafsson, P. (2001) CP43', the isiA gene product, functions as an excitation energy dissipator in the cyanobacterium *Synechococcus* sp. PCC 7942. *Photochem Photobiol* 74:431-437.

Santarius, K. A. (1992) Freezing of isolated thylakoid membranes in complex media. VIII. Differential cryoprotection by sucrose, proline and glycerol. *Physiol Plant* 84: 87-93.

Santoni, E. , Jakopitsch, C. , Obinger, C. , and Smulevich, G. (2004) Comparison between catalase-peroxidase and cytochrome c peroxidase. The role of hydrogen bond networks for protein stability and catalysis. *Biochemistry* 43: 5792-5802.

Santos, S. , and da Costa, M. S. (2002) Compatible solutes of organisms that live in hot saline environments. *Environ Microbiol* 4: 501-509.

Sassoon, N. , Árie, J. P. , and Betton, J. M. (1999) PDZ domains determine the native oligomeric structure of the DegP (HtrA) peptidase. *Mol Microbiol* 33: 583-589.

Sato, M. , Nimura-Matsune, K. , Watanabe, S. , Chibazakura, T. , and Yoshikawa, H. (2007) Expression analysis of multiple dnaK genes in the cyanobacterium *Synechococcus elongatus* PCC 7942. *J Bacteriol* 189: 3751-3758.

Sato, N. (1994) A cold-regulated cyanobacterial gene cluster encodes RNA-binding protein and ribosomal protein S21. *Plant Mol Biol* 18:165-170.

Sato, N. (1995) A family of cold-regulated RNA-binding protein genes in the cyanobacterium *Anabaena variabilis* M3. *Nucleic Acids Res* 23:2161-2167.

Sato, N. , and Maruyama, K. (1997) Differential regulation by low temperature of the gene for an RNA-binding protein, rbpA3, in the cyanobacterium *Anabaena variabilis* strain M3. *Plant Cell Physiol* 38: 81-86.

Sato, N. , and Murata, N. (1980) Temperature shift-induced responses in lipids in the blue-green alga, *Anabaena variabilis*. The central role of diacylmonogalactosylglycerol in thermo-adaptation. *Biochim Biophys Acta* 619: 353-366.

Sato, N. , and Murata, N. (1981) Studies on the temperature shift induced desaturation of fatty acids in monogalactosyl diacylglycerol in the blue-green alga (cyanobacterium), *Anabaena variabilis*. *Plant Cell Physiol* 22:1043-1050.

Sato, N. , and Nakamura, A. (1998) Involvement of the 5'-untranslated region in cold-regulated expression of the rbpA1 gene in the cyanobacterium *Anabaena variabilis* M3. *Nucleic Acids Res* 26: 2192-2199.

Sato, N. , Maruyama, K. , Nishiyama, Y. , and Murata, N. (1997a) Identification of a cold-regulated RNA binding protein from the marine cyanobacterium *Synechococcus* sp. PCC 7002 (Cyanophyta). *J Plant Res* 110: 405-410.

Sáto, N. , Maruyama, K. , Nishiyama, Y. , and Murata, N. (1997a) Identification of a cold-regulated RNA binding protein from the marine cyanobacterium *Synechococcus* sp. PCC 7002 (Cyanophyta). *J Plant Res* 110: 405-410.

Sáto, N. , Tachikawa, T. , Wada, A. , and Tanaka, A. (1997b) Temperature-dependent regulation of the ribosomal small-subunit protein S21 in the cyanobacterium *Anabaena variabilis* M3. *J Bacteriol* 179: 7063-7071.

Satoh, K. , Hiral, M. , Nishio, J. , Yamaji, T. , Kashino, Y. , and Koike, H. (2002) Recovery of photosynthetic systems during rewetting is quite rapid in a terrestrial cyanobacterium *Nostoc commune*. *Plant Physiol* 43:170-176.

Scheibe, R. (1987) NADP⁺-malate dehydrogenase in C3-plants: Regulation and role of a Kght-activated enzyme. *Physiol Plant* 71:393-400.

Schelin, J. , Lindmark, E. , and Clarke, A. K. (2002) The ClpP multigene family for the ATP-dependent Clp protease in the cyanobacterium *Synechococcus*. *Microbiology* 148: 2255-2265.

Scherer, S. , and Potts, M. (1989) Novel water stress protein from a desiccation-tolerant cyanobacterium: purification and partial characterization. *J Biol Chem* 264:12546-12553.

Scherer, S. , Ernst, A. , Chen, T.-W. , and Boger, P. (1984). Rewetting of drought-resistant blue-green algae: time course of water uptake and reappearance of respiration, photosynthesis, and nitrogen fixation. *Oecologia* 62: 418-423.

Schindelin, H. , Jiang, W. , Inouye, M. , and Heinemann, U. (1994) Crystal structure of CspA., the major cold shock protein of *Escherichia coli*. *Proc Natl Acad Sci USA* 91: 5119-5123.

Schmid, S. R. , and Linder, P. (1992) D-E-A-D protein family of putative RNA helicases. *Mol Microbiol* 6:283-292.

Schmidt, M. , Buchner, J. , Todd, M. J. , Lorimer, G. H. , and Viitanen, P. V. (1994) On the role of GroES in the chaperonin-assisted folding reaction. *J Biol Chem* 269:10304-10311.

Schirmer, E. C. , Glover, J. R. , Singer, M. A. , and Lindquist, S. (1996) HSP100/Clp proteins: a common mechanism explains diverse functions. *Trends Biol Sci* 21:289-296.

Schroder, E. , and Ponting C. P. (1998) Evidence that peroxiredoxins are novel members of the thioredoxin fold superfamily. *Protein Sci* 7: 2465-2468.

Schroder, E. , Littlechild, J. A. , Lebedev, A. A. , Errington, N. , Vagin, A. A. , and Isupov, M. N. (2000) Crystal structure of decameric 2-Cys peroxiredoxin from human erythrocytes at 1.7 Å resolution. *Structure* 8: 605-615.

Schroder, K. , Graumann, P. , Schnuchel, A. , Holak, T. A. , and Marahiel, M. A. (1995) Mutational analysis of the putative nucleic acid-binding surface of the cold-shock domain, cspb, revealed an essential role of aromatic and basic residues in binding of single-stranded-DNA containing the y-box motif. *Mol Microbiol* 16: 699-708. doi: 10.1111/j.1365-2958.1995.tb02431.x

Schubert, H. , Fulda, S. , and Hagemann, M. (1993) Effects of adaptation to different salt concentrations on photosynthesis and pigmentation of the cyanobacterium *Synechocystis* sp. PCC 6803. *J Plant Physiol* 141: 291-295.

Schurmann, P. , and Buchanan, B. B. (2008) The ferredoxin/thioredoxin system of oxygenic photosynthesis. *Antioxid Redox Signal* 10:1235-1274.

Schwartz, S. H. , Black, T. A. , Jáger, K. , Panoff, J.-M. , and Wolk, C. P. (1998) Regulation of an osmoticum-responsive gene in *Anabaena* sp. strain PCC 7120. *J Bacteriol* 180: 6332-6337.

Seaton, B. L. , and Vickery L. E. (1994) A gene encoding a DnaK/hsp70 homolog in *Escherichia coli*. *Proc Natl Acad Sci USA* 91:2066-2070.

Seckbach, J. . (ed.) (2007) *Algae and Cyanobacteria in Extrême Environments Vol 11 Cellular Origin, Life in Extrême Habitats and Astrobiology*. Springer, Dordrecht, The Netherlands.

Servant, P. , Grandvalet, C. , and Mazodier, P. (2000) The RheA repressor is the thermosensor of the HSP18 heat shock response in *Streptomyces albus*. *Proc Natl Acad Sci USA* 97: 3538-3543.

Servant, P. , Rapoport, G. , and Mazodier, P. (1999) RheA., the repressor of hsp18 in *Streptomyces albus* G. *Microbiology* 145: 2385-2391.

Shanklin, I. , DeWitt, N. D. , and Flanagan, J. M. (1995) The stroma of higher plant plastids contain ClpP and ClpC., functional homologs of *Escherichia coli* ClpP and ClpA: an archetypal two-component ATP-dependent protease. *Plant Cell* 7: 1713-1722.

Shapiguzov, A. , Lyukevich, A. A. , Allakhverdiev, S. I. , Sergeyenkov, T. V. , Suzuki, I. , Murata, N. , and Los, D. A. (2005) Osmotic shrinkage of cells of *Synechocystis* sp. PCC 6803 by water efflux via aquaporins regulates osmotic stress gene expression. *Microbiology* 151: 447-455. doi:10.1099/mic.0.27530-0

Shaw, E. , Hill, D. R. , Brittain, N. , Wright, W. I. , Táuber, U. , Marand, H. , Helm, R. F. , and Potts, M. (2003) Unusual water flux in the extracellular polysaccharide of the cyanobacterium *Nostoc commune*. *Appl Environ Microbiol* 69: 5679-5684.

Scholnick, S. , Shaked, Y. , and Keren, N. (2007) A role for mrgA., a DPS family protein, in the internal transport of Fe in the cyanobacterium *Synechocystis* sp. PCC 6803. *Biochim Biophys Acta* 1767: 814-819.

Scholnick, S. , Summerfield, T. C. , Reytman, L. , Sherman, L. A. , and Keren, N. (2009) The mechanism of iron homeostasis in the unicellular cyanobacterium *Synechocystis* sp. PCC 6803 and its relationship to oxidative stress. *Plant Physiol* 150: 2045-2056.

Shen, J.-R. , Qian, M. , Inoue, Y. , and Burnap, R. L. (1998) Functional characterization of *Synechocystis* sp. PCC 6803 DpsbU and DpsbV mutants reveals important roles of cytochrome c-550 in cyanobacterial oxygen evolution. *Biochemistry* 37: 1551-1558.

Shen-Miller, I. , Mudgett, M. B. , Schopf, J. W. , Clarke, S. , and Berger, R. (1995) Exceptional seed longevity and robust growth: Ancient sacred lotus from China. *Am J Bot* 82:1367-1380.

Shestakov, S. V. , Anbudurai, P. R. , Stanbekova, G. E. , Gadzhiev, A. , Lind, L. K. , and Pakrasi, H. B. (1994) Molecular cloning and characterization of the ctpA gene encoding a carboxyl-terminal processing peptidase. Analysis of a spontaneous photosystem II-deficient mutant strain of the cyanobacterium *Synechocystis* sp. PCC 6803. *J Biol Chem* 269: 19354-19359.

Shiraishi, T. , Takahashi, M.-A. , and Asada, K. (1994) Generation of O₂ anion radicals and hydroxyl radicals in chloroplast thylakoids. In: Asada, K. , and Yoshikawa, T. . (Eds.) *Frontiers of Reactive Oxygen Species in Biology and Medicine*. Excerpta Medica, Amsterdam, The Netherlands, pp. 31-32.

Shirkey B. , Kovarik, D. P. , Wright, D. I. , Wilmoth, G. , Prickett, T. F. , Helm, R. F. , Gregory, E. M. and Potts, M. (2000). Active Fe-containing superoxide dismutase and abundant sodF mRNA in *Nostoc commune* (Cyanobacteria) after years of desiccation. *J Bacteriol* 182:189-197.

Shirkey, B. , McMaster, N. I. , Smith, S. C. , Wright, D. I. , Rodriguez, H. , Jaruga, P. , Birincioglu, M. , Helm, R. F. , and Potts, M. (2003) Genomic DNA of *Nostoc commune* (cyanobacteria) becomes covalently modified during long-term (decades) desiccation but is protected from oxidative damage and degradation. *Nucleic Acids Res* 31: 2995-3005.

Shoumskaya, M. A. , Paithoonrangsarit, K. , Kanesaki, Y. , Los, D. A. , Zinchenko, V. V. , Tanticheran, M. , Suzuki, I. , and Murata, N. (2005) Identical Hik-Rre systems are involved in perception and transduction of salt signals and hypersmotic signals but regulate the

expression of individual genes to different extents in *Synechocystis*. *J Biol Chem* 280: 21531-21538.

Sigler, W. V. , Bachofen, R. , and Zeyer, J. (2003) Molecular characterization of endolithic cyanobacteria inhabiting exposed dolomite in central Switzerland. *Environ Microbiol* 5: 618-627.

Silva, R. , Choi, Y. J. , Hassan, H. A. , and Nixon, P. J. (2002) Involvement of the HtrA family of proteases in the protection of the cyanobacterium *Synechocystis* PCC 6803 from light stress and in the repair of photosystem II. *Phil Trans R Soc B London* 357:1461-1467.

Silva, P. , Thompson, E. , Bailey, S. , Kruše, O. , MuUineaux, C. W. , Robinson, C. , Mann, N. H. , and Nixon, R. J. (2003) FtsH is involved in the early stages of repair of photosystem II in *Synechocystis* sp PCC 6803. *Plant Cell* 15:2152-2164.

Singer, M. A. , and Lindquist, S. (1998a) Thermotolerance in *Saccharomyces cerevisiae*: the Yin and Yang of trehalose. *Trends Biotechnol* 16: 460-468.

Singer, M. A. , and Lindquist, S. (1998b) Multiple effects of trehalose on protein folding in vitro and in vivo. *Mol Cell* 1: 639-648.

Singh, A. K. , Li, H. , and Sherman, L. A. (2004). Microarray analysis and redox control of gene expression in the cyanobacterium *Synechocystis* sp. PCC 6803. *Physiol Plant* 120: 27-35.

Singh, D. P. , and Kshatriya, K. (2002) NaCl-induced oxidative damage in the cyanobacterium *Anabaena doliolum*. *Curr Microbiol* 44: A11-A17.

Singh, S. C. , Sinha, R. P. , and Háder, D-P. (2002) Role of lipids and fatty acids in stress tolerance in cyanobacteria. *Acta Protozool* 41: 297-308.

Singh, S. P. , Kisch, M. , Sinha, R. P. , and Háder, D.-P. (2008) Effects of abiotic stressors on synthesis of the mycosporine-like amino acid shinorine in the cyanobacterium *Anabaena variabilis* PCC 7937. *Photochem Photobiol* 84:1500-1505.

Singh, S. P. , Klisch, M. , Sinha, R. P. , and Háder, D.-P. (2009) Genome mining of mycosporine-like amino acid (MAA) synthesizing and non-synthesizing cyanobacteria. *Genomics* 95:120-128. doi: org/10.1016/j.ygeno.2009.10.002

Sinha, R. P. , Ambasht, N. K. , Sinha, J. P. , Klisch, M. , and Háder, D.-P. (2003) UV-B-induced synthesis of mycosporine-like amino acids in three strains of *Nodularia* (cyanobacteria). *J Photochem Photobiol B* 71: 51-58.

Sinha, R. P. , Klisch, M. , Helbling, E. W. , and Háder, D.-P. (2001) Induction of mycosporine-like amino acids (MAAs) in cyanobacteria by solar ultraviolet-B radiation. *J Photochem Photobiol B* 60:129-135.

Sinha, R. P. , Singh, S. P. , and Háder, D-P. (2007) Database on mycosporines and mycosporine-like amino acids (MAAs) in fungi, cyanobacteria, macroalgae, phytoplankton and animals. *J Photochem Photobiol B Biol* 89: 29-35.

Sippola, K. , Kanervo, E. , Murata, N. , and Aro, E.-M. (1998) A genetically engineered increase in fatty acid unsaturation in *Synechococcus* sp. PCC 7942 allows exchange of D1 protein forms and sustenance of photosystem II activity at low temperature. *Eur J Biochem* 251: 641-648.

Sivá, V. , Rao, K. , Brand, J. J. , and Myers, J. (1977) Cold shock syndrome in *Anacystis nidulans*. *Plant Physiol* (Bethesda) 59: 965-969.

Skorko-Glonek, J. , Lipinska, B. , Krzewski, K. , Zolse, G. , Bertoli, E. , and Tanfani, F. (1997) HtrA heat stress protease interacts with phospholipid membranes and undergoes conformational changes. *J Biol Chem* 272: 8974-8982.

Skorko-Glonek, J. , Zurawa, D. , Kuczwara, E. , Wozniak, M. , Wypych, Z. , and Lipinska, B. (1999) The *Escherichia coli* heat stress peptidase HtrA participates in defense against oxidative stress. *Mol Gen Genet* 262: 342-350.

Sokolenko, A. , Pojidaeva, E. , Zinchenko, V. , Panichkin, V. , Glaser, V. M. , Herrmann, R. G. , and Shestakov, S. V. (2002) The gene complement for proteolysis in the cyanobacterium *Synechocystis* sp. PCC 6803 and *Arabidopsis thaliana* chloroplasts. *Curr Genet* 41:291-310.

Soontharapirakkul, K. , Promden, W. , Yamada, N. , Kageyama, H. , Incharoensakdi, A. , Iwamoto-Kihara, A. , and Takabe, T. (2011) Halotolerant cyanobacterium *Aphanethece halophytica* contains an Na⁺-dependent F1F0-ATP synthase with a potential role in salt stress tolerance. *J Biol Chem* 286:10169-10176.

Spieß, C. , Beil, A. , and Ehrmann, M. (1999) A temperature-dependent switch from chaperone to peptidase in a widely conserved heat stress protein. *Cell* 97:339-347.

Squires, C. , and Squires, C. L. (1992) The Clp proteins: proteolysis regulators or molecular chaperones? *J Bacteriol* 174: 1081-1085.

Stal, L. J. , and Reed, R. H. (1987) Low molecular mass carbohydrate accumulation in cyanobacteria from marine microbial mat in response to salt. *FEMS Microbiol Lett* 45: 305-312.

Stanne, T. M. , Pojidaeva, E. , Andersson, F. I. , and Clarke, A. K. (2007) Distinctive types of ATP-dependent Clp proteases in cyanobacteria. *J Biol Chem* 282:14394-14402.

Steinitz, Y. , Mazor, Z. , and Shilo, M. (1979) A mutant of the cyanobacterium *Plectonema boryanum* resistant to photooxidation. *Plant Sci Lett* 16:327-335.

Stewart, G. R. , Wernisch, L. , Stabler, R. , Mangan, J. A. , Hinds, J. , Laing, K. G. , Young, D. B. , and Butcher, P. D. (2002) Dissection of the heat-shock response in *Mycobacterium tuberculosis* using mutants and microarrays. *Microbiology* 148:3129-3138.

Stolz, J. F. (1990) Distribution of phototrophic microbes in the fiat laminated microbial mat at Laguna Figueroa, Baja California, Mexico. *BioSystems* 23:345-357.

Stone, J. R. , and Yang, S. (2006) Hydrogen peroxide: a signaling messenger. *Antioxid Redox Signál* 8: 243-270. doi:10.1089/ars2006.8.243

Stork, T. , Michel, K. R. , Pistorius, E. K. , and Dietz, K. J. (2005) Bioinformatic analysis of the genomes of the cyanobacteria *Synechocystis* sp. PCC 6803 and *Synechococcus elongatus* PCC 7942 for the presence of peroxiredoxins and their transcript regulation under stress. *J Exp Bot* 422: 3193-3206.

Storz, G. , and Zheng, M. (2000) Oxidative stress. In: Storz, G., and Hengge-Aronis, R. (Eds.) *Bacterial Stress Response*. ASM. Press , Washington, D.C. USA. pp. 47-59.

Strandling, D. A. , Thygeson, T. , Walker, J. A. , Smith, B. N. , Hansen, L. D. , Criddle, R. S. , and Pendleton, R. L. (2002) Cryptogamic crust metabolism in response to temperature, water vapour and liquid water. *Thermochem Acta* 394: 219-225.

Strauch, K. L. , and Beckwith, J. (1988) An *Escherichia coli* mutation preventing degradation of abnormal periplasmic proteins. *Proc Natl Acad Sci USA* 85:1576-1580.

Strauch, K. L. , Johnson, K. , and Beckwith, J. (1989) Characterization of degP, a gene required for proteolysis in the cell envelope and essential for growth of *Escherichia coli* at high temperature. *J Bacteriol* 171: 2689-2696.

Straus, N. A. (1994) Iron deprivation: physiology and gene regulation. In: Bryant, D.A. . (Ed.) *The Molecular Biology of Cyanobacteria*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 731-775.

Strom, A. R. (1998) Osmoregulation in the model organism *Escherichia coli* genes governing the synthesis of glycine betaine and trehalose and their use in metabolic engineering of stress tolerance. *J Biosci* 23:437-445. doi:10.1007/BF02936137

Strom, A. R. , and Kaasen, I. (1993) Trehalose metabolism in *Escherichia coli*: stress protection and stress regulation of gene expression. *Mol Microbiol* 8: 205-210.

Stulp, B. K. , and Potts, M. (1987) Stability of nucleic acids in immobilized and desiccated *Nostoc commune* UTEX 584 (cyanobacteria). *FEMS Microbiol Lett* 41: 241-245.

Sudhir, P.-R. , Pogoryelov, D. , Kovács, L. , Garáb, G. , and Murhy, S. D. S. (2005) The effects of salt stress on photosynthetic electron transport and thylakoid membrane proteins in the cyanobacterium *Spirulina platensis*. *J Biochem Mol Biol* 38: 481-485.

Sueoka, K. , Yamazaki, T. , Hiyama, T. , and Nakamoto, H. (2009) The NADPH hioredoxin reductase C functions as an electron donor to 2-Cys peroxiredoxin in a thermophilic cyanobacterium *Thermostynechococcus elongatus* BP-1. *Biochem Biophys Res Commun* 380: 520-524. doi:10.1016/j.bbrc.2009.01.091

Sugita, M. , and Sugiura, M. (1994) The existence of eukaryotic ribonucleoprotein consensus sequence-type RNA-binding proteins in a prokaryote, *Synechococcus* 6301. *Nucleic. Acids Res* 22: 25-31.

Summerfield, T. C. , and Sherman, L. A. (2008) Global transcriptome analysis of the alkali-tolerant cyanobacterium *Synechocystis* sp. strain PCC 6803. *Appl Environ Microbiol* 74: 5276-5284.

Summerfield, T. C. , Shand, J. A. , Bentley F. K. , and Eaton-Rye, J. J. (2005) PsbQ (S111638) in *Synechocystis* sp. PCC 6803 is required for photosystem II activity in specific mutants and in nutrient-limiting conditions. *Biochemistry* 44: 805-815.

Suzuki, I. , Kanesaki, Y. , Mikami, K. , Kanehisa, M. , and Murata, N. (2001) Cold-regulated genes under control of the cold sensor Hik33 in *Synechocystis*. *Mol Microbiol* 40: 235-244.

Suzuki, I. , Kanesaki, Y. , Hayashi, H. , Halí, J. J. , Simon, W. J. , Slabas, A. R. , and Murata, N. (2005) The histidine kinase Hik34 is involved in thermotolerance by regulating expression of heat shock genes in *Synechocystis*. *Plant Physiol* 138: 1409-1421.

Suzuki, I. , Los, D. A. , and Murata, N. (2000a) Perception and transduction of low temperature signals to induce desaturation of fatty acids. *Biochem Soc Trans* 28: 628-630.

Suzuki, I. , Los, D. A. , Kanesaki, Y. , Mikami, K. , and Murata, N. (2000b) The pathway for perception and transduction of low-temperature signals in *Synechocystis*. *Embo J* 19:1327-1334.

Suzuki, I. , Simon, W. J. , and Slabas, A. R. (2006) The heat shock response of *Synechocystis* sp. PCC 6803 analysed by transcriptomics and proteomics. *J Exp Bot* 57:1573-1578.

Suzuki, T. , Yoshimura, H. , Hisabori, T. , and Ohmori, M. (2004) Two cAMP receptor proteins with different biochemical properties in the filamentous cyanobacterium *Anabaena* sp. PCC 7120. *FEBS Lett* 571:154-160.

Suzuki, T. , Yoshimura, H. , Ehira, S. , Ikeuchi, M. , and Ohmori, M. (2007) AnCrpA, a c AMP receptor protein, regulates wif-related gene expression in the cyanobacterium *Anabaena* sp. strain PCC 7120 grown with nitrate. *FEBS Lett* 581:21-28.

Symons, M. C. R. (1991) Free radicals in biological systems. In: Dreosti, I. E. . (Ed.) *Trace Elements, Micronutrients and Free Radicals*. Humana Press, Totowa, NJ, USA. pp. 1-24.

Szalontai, B. , Nishiyama, Y. , Gombos, Z. , and Murata, N. (2000) Membrane dynamics as seen by fourier transform infrared spectroscopy in a cyanobacterium, *Synechocystis* PCC 6803. The effects of lipid unsaturation and the protein-to-lipid ratio. *Biochim Biophys Acta* 1509: 409-419.

Takaichi, S. , Maoka, T. , and Mochimaru, M. (2009) Unique carotenoids in the terrestrial cyanobacterium *Nostoc commune* NIES-24: 2'-hydroxymyxol-2'-fucoside, nostoxanthin and canthaxanthin. *Curr Microbiol* 59: 413-419.

Takeyama, H. , Burgess, J. G. , Sudo, H. , Soda, K. , and Matsunaga, T. (1991) Salinity dependent copy number increase of a marine cyanobacterial endogenous plasmid. *FEMS Microbiol Lett* 90: 95-98.

Tamaru, Y. , Takáni, Y. , Yoshida, T. , and Sakamoto, T. (2005) Crucial role of extracellular polysaccharides in desiccation and freezing tolerance in the terrestrial cyanobacterium *Nostoc commune*. *Appl Environ Microbiol* 71: 7327-7333.

Tamoi, M. , Kurotaki, H. , and Fukamizo, T. (2007) [3-1,4-Glucanase-like protein from the cyanobacterium *Synechocystis* PCC 6803 is a [3-1,3,4-glucanase and functions in salt stress tolerance. *Biochem J* 405:139-146.

Tanaka, N. , and Nakamoto, H. (1999) HtpG is essential for the thermal stress management in cyanobacteria. *FEBS Lett* 458: 117-123.

Tanner, N. K. , and Linder, P. (2001) DEXD/H box RNA helicases: from generic motors to specific dissociation functions. *Mol Cell* 8: 251-262

Tanner, N. K. , Cordin, O. , Banroques, J. , Doire, M. , and Linder, P. (2003) The Q motif: a newly identified motif in DEAD box helicases may regulate ATP binding and hydrolysis. *Mol Cell* 11:127-138.

Taranto, P. A. , Keenan, T. W. , and Potts, M. (1993). Rehydration induces rapid onset of lipid biosynthesis in desiccated *Nostoc commune* (Cyanobacteria). *Biochim Biophys Acta* 1168:228-237.

Tasaka, Y. , Gombos, Z. , Nishiyama, Y. , Mohanty P. , Ohba, T. , Ohki, K. , and Murata, N. (1996) Targeted mutagenesis of acyl lipid desaturases in *Synechocystis*: evidence for the important roles of polyunsaturated membrane lipids in growth, respiration and photosynthesis. *Embo J* 15: 6416-6425.

Taylor, B. L. , and Zhulin, I. B. (1999) PAS domains: internal sensors of oxygen, redox potential, and light. *Microbiol Mol Biol Rev* 63:479-506.

Tel-Or, E. , Huflejt, M. , and Packer, L. (1985) The role of glutathione and ascorbate in hydroperoxide removal in cyanobacteria. *Biochem Biophys Res Commun* 132: 533-539.

Thevelein, J. M. (1984) Regulation of trehalose mobilisation in fungi. *Microbiol Rev* 48: 42-59.

Thomas, D. J. , Avenson, T. J. , Thomas, J. B. , and Herbert, S. K. (1998) A cyanobacterium lacking iron superoxide dismutase is sensitized to oxidative stress induced with methyl viologen but is not sensitized to oxidative stress induced with norflurazon. *Plant Physiol* 116:1593-1602.

Thomas, J. A. , Poland, B. , and Honzatko, R. (1995) Protein sulfhydryls and their role in the antioxidant function of protein S-thiolation. *Arch Biochem Biophys* 319:1-9.

Thompson, M. W. , and Maurizi, M. R. (1994) Activity and specificity of *Escherichia coli* ClpAP protease in cleaving model peptide substrates. *J Biol Chem* 269:18201-18208.

Tichy, M. , and Vermaas, W. (1999) In vivo role of catalase-peroxidase in *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 181: 1875-1882.

Tirkey J. , and Adhikary S. P. (2005) Cyanobacteria in biological soil crusts of India. *Curr Sci* 89: 515-521.

Tiwari, B. S. and Tripathi, S. N. (1998) Effect of hydration and dehydration and dynamics of some physiological reactions in desiccation tolerant cyanobacterium *Scytonema geitleri*. *Indian J Biochem Biophys* 35:172-178.

Tiwari, B. S. , and Tripathi, S. N. (2001) Photosynthetic activities of roof-top desiccation tolerant cyanobacterium *Scytonema geitleri* at varying hydration levels. *Algae* 16: 445-455.

Tiwari, G. L. (1972) Morphology and life history of *Chroococcidiopsis* Geitler (Chroococcales). *Hydrobiologia* 40:177-182.

Tomb, J. E. , White, O. , Kerlavage, A. R. , Clayton, R. A. , Sutton, G. G. , Fleischmann, R. D. , Ketchum, K. A. , Klenk, H. P. , Gill, S. , Dougherty B. A. , Nelson, K. , Quackenbush, J. , Zhou, L. , Kirkness, E. E. , Peterson, S. , Loftus, B. , Richardson, D. , Dodson, R. , Khalak, H. G. , Glodek, A. , McKenney K. , Fitzgerald, L. M. , Lee, N. , Adams, M. D. , Hickey E. K. , Berg, D. E. , Gocayne, J. D. , Utterback, C. R. , Peterson, J. D. , Kelley J. M. , Cotton, M. D. , Weidman, J. M. , Fujii, C. , Bowman, C. , Watthey L. , Wallin, E. , Hayes, W. S. , Borodovsky M. , Karp, P. D. , Smih, H. O. , Fraser, C. M. , and Venter, J. C. (1997) The complete genome sequence of the gastric pathogen *Helicobacter pylori*. *Nature (London)* 388: 539-547.

Tomoyasu, T. , Yamanaka, K. , Murata, K. , Suzuki, T. , Boulouc, P. , Kato, A. , Niki, H. , Hiraga, S. , and Ogura, T. (1993) Topology and subcellular localization of FtsH protein in *Escherichia coli*. *J Bacteriol* 175:1352-1357.

Tomoyasu, T. , Ogura, T. , Tatsuta, T. , and Bukau, B. (1998) Levels of DnaK and DnaJ provide tight control of heat shock gene expression and protein repair in *Escherichia coli*. *Mol Microbiol* 30: 567-581.

Torok, Z. , Goloubinoff, P. , Horváth, I. , Tsvetkova, N. M. , Glatz, A. , Balogh, G. , Varvasovszki, V. , Los, D. A. , Vierling, E. , Crowe, J. H. , and Vigh, L. (2001) *Synechocystis* Hsp17 is an amphitropic protein that stabilizes heat-stressed membranes and binds denatured proteins for subsequent chaperone-mediated refolding. *Proc Natl Acad Sci USA* 98: 3098-3103.

Tripathi, S. N. , and Srivastava, P. (2001) Presence of stable active scavenging enzymes superoxide dismutase, ascorbate peroxidase and catalase in a desiccation-tolerant cyanobacterium *Lyngbya arboricola* under dry state. *Curr Sci* 81: 197-200.

Tripathi, S. N. , Tiwari, B. S. , and Talpasayi, E. R. S. (1991) Growth of cyanobacteria (blue-green algae) on urban buildings. *Energy and Buildings* 15:499-505.

Tripathy P. , Amarpalli, R. , and Adhikary, S. P. (1997) Survey of epilithic bluegreen algae (cyanobacteria) from temples of India and Nepal. *Arch Hydrobiol Algol Stud* 87: 43-57.

Tripathy, P. , Roy A. , Anand, N. , and Adhikary, S. P. (1999) Blue-green algal flora on the rock surface of temples and monuments of India. *Feddes Repertorium* 110:133-144.

Trüper, H. G. , and Galinski, E. A. (1990) Biosynthesis and fate of compatible solutes in extremely halophilic phototrophic eubacteria. *FEMS Microbiol Rev* 75:247-254.

Tsvetkova, N. M. , Horváth, I. , Torok, Z. , Wolkers, W. R. , Balogi, Z. , Shigapova, N. , Crowe, L. M. , Tablin, R. , Vierling, E. , Crowe, J. H. , and Vigh, L. (2002) Small heat-shock proteins regulate membrane lipid polymorphism. *Proc Natl Acad Sci USA* 99:13504-13509.

Tyystjärvi, T. , Tyystjärvi, E. , Ohad, L. , and Aro, E. (1998) Exposure of *Synechocystis* 6803 cells to series of single turnover flashes increases the *psbA* transcript level by activating transcription and down-regulating *psbA* mRNA degradation. *FEBS Lett* 436: 483-487.

Usher, K. M. , Bergman, B. , and Raven, R. A. (2007) Exploring cyanobacterial mutualisms. *Annu Rev Ecol Evol Syst* 38: 255-273.

Van Bogelen, R. , and Neidhardt, R. C. (1990) Ribosomes as sensors of heat and cold shock in *Escherichia coli*. *Proc Natl Acad Sci USA* 87: 5589-5593.

Vandenbroucke, K. , Robbens, S. , Vandepoele, K. , Inzé, D. , Van de Peer , and Van Breusegen, R. (2008) Hydrogen peroxide-induced gene expression across Kingdoms: A comparative analysis. *Mol Biol Evol* 25: 507-516.

van Montfort, R. L. M. , Basha, E. , Friedrich, K. L. , Slingsby C. , and Vierling, E. (2001) Crystal structure and assembly of a eukaryotic small heat shock protein. *Nat Struct Biol* 8:1025-1030.

van Thielen, N. , and Garbary D. J. (1999) Life in the rocks: endolithic algae. In: Seckbach, J. . (Ed.) *Enigmatic Microorganisms and Life in Extreme Environments*. Kluwer Academic Publishers, Dordrecht, The Netherlands. pp. 243-253

Varvasovszki, V. , Glatz, A. , Shigapova, N. , Jósavay K. , Vigh, L. , and Horváth, I. (2003) Only one dnaK homolog, dnaK1 is active transcriptionally and is essential in *Synechocystis*. *Biochem Biophys Res Commun* 305: 641-645.

Vasishta, R. C. (1968) Thermal cyanophyceae of India. *Phykos* 7:198-241.

Veal, E. A. , Day A. M. , and Morgan, B. A. (2007) Hydrogen peroxide sensing and signaling. *Mol Cell* 26:1-14.

Veal, E. A. , Findlay V. J. , Day, A. M. , Bozonet, S. M. , Evans, J. M. , Quinn, J. , and Morgan, B. A. (2004) A 2-Cys peroxiredoxin regulates peroxide-induced oxidation and activation of a stress-activated MAP kinase. *Mol Cell* 15:129-139.

Veinger, L. , Diamant, S. , Buchner, J. , and Goloubinoff, R. (1998) The small heat-shock protein IbpB from *Escherichia coli* stabilizes stress-denatured proteins for subsequent refolding by a multichaperone network. *J Biol Chem* 273:11032-11037.

Venter, J. C. , Remington, K. , Heidelberg, J. R. , Halpern, A. L. , Rusch, D. , Eisen, J. A. , Wu, D. , Paulsen, I. , Nelson, K. E. , Nelson, W. , Fouts, D. E. , Levy S. , Knap, A. H. , Lomas, M. W. , Nealson, K. , White, O. , Peterson, J. , Hoffman, J. J. , Parsons, R. , Baden-Tillson, H. , Pfannkoch, C. , Rogers, Y. H. , and Smith, H. O. (2004) Environmental genome shotgun sequencing of the Sargasso Sea. *Science* 304: 66-74.

Viale, A. M. , Arakaki, A. K. , Soncini, R. C. , and Ferreyra, R. G. (1994) Evolutionary relationships among eubacterial groups as inferred from GroEL (chaperonin) sequence comparisons. *Int J Syst Bacteriol* 44: 527-533.

Vigh, L. , Los, D. A. , Horváth, I. , and Murata, N. (1993) The primary signal in the biological perception of temperature: Pd-catalyzed hydrogenation of membrane lipids stimulated the expression of the *desA* gene in *Synechocystis* PCC 6803. *Proc Natl Acad Sci USA* 90: 9090-9094.

Vigh, L. , Maresca, B. , and Harwood, J. L. (1998) Does the membrane's physical state control the expression of heat shock and other genes? *Trends Biochem Sci* 23:369-374.

Vigh, L. O. , Nakamoto, H. , Landry J. , Gomez-Munoz, A. , Harwood, J. L. , and Horváth, I. (2007) Membrane regulation of stress response from prokaryotic models to mammalian cells. *Ann New York Acad Sci* 1113:40-51.

Vincent, W. R. , Gibson, J. A. , Pienitz, R. , ViUeneuve, V. , Broady P. A. , Hamilton, P. B. , and Howard-Wilkins, C. (2000) The shelf microbial ecosystems in the High Arctic and implications for life on snowball Earth. *Naturwissenschaften* 87:137-141.

Vincent, W. R. , Mueller, D. R. , and Bonilla, S. (2004) Ecosystems on ice: the microbial ecology of Markham Ice Shelf in the high Arctic. *Cryobiology* 48:103-112.

Vinnemeier, J. , and Hagemann, M. (1999) Identification of salt-regulated genes in the genome of the cyanobacterium *Synechocystis* sp. strain PCC 6803 by subtractive RNA hybridization. *Arch Microbiol* 172: 377-386.

Vinnemeier, J. , Kunert, A. , and Hagemann, M. (1998) Transcriptional analysis of the *isiAB* operon in salt-stressed cells of the cyanobacterium *Synechocystis* sp. PCC 6803. *FEMS Microbiol Lett* 169:323-330.

Vlasits, J. , Furtmüller, P. G. , Jakopitsch, C. , Zámacký, M. , and Obinger, C. (2010) Probing hydrogen peroxide oxidation kinetics of wild-type *Synechocystis* catalase-peroxidase (KatG) and selected variants. *Biochem Biophys Acta* 1804: 799-805.

Vlasits, J. , Jakopitsch, C. , Schwanninger, M. , Holubæk, P. , and Obinger, C. (2007) Hydrogen peroxide oxidation by catalase-peroxidase follows a non-scrambling mechanism. *FEBS Lett* 581:320-324.

Vonshak, A. , Guy R. , and Guy M. (1988) The response of the filamentous cyanobacterium *Spirulina platensis* to salt stress. *Arch Microbiol* 150:417-420.

Vránová, E., Inzé, D., and Van Breusegem, R (2002) Signál transduction during oxidative stress. *J Exp Bot* 53:1227-1236.

Wada, H. , and Murata, N. (1989) *Synechocystis* PCC 6803 mutants defective in desaturation of fatty acids. *Plant Cell Physiol* 30: 971-978.

Wada, H. , and Murata, N. (1990) Temperature-induced changes in the fatty acids composition of the cyanobacterium, *Synechocystis* PCC 6803. *Plant Physiol* 92:1062-1069.

Wada, H. , Avelange-Macherel, M. H. , and Murata, N. (1993) The *desA* gene of the cyanobacterium *Synechocystis* sp. strain PCC 6803 is the structural gene for A12 desaturase. *J Biol Chem* 175: 6056-6058.

Wada, H. , Gombos, Z. , and Murata, N. (1990) Enhancement of chilling tolerance of a cyanobacterium by genetic manipulation of fatty acid desaturation. *Nature (London)* 347: 200-203.

Wada, H. , Gombos, Z. , and Murata, N. (1994) Contribution of membránì lipids to the ability of the photosynthetic machinery to tolerate temperature stress. *Proe Nati Acad Sci USA* 91: 4273-4277.

Wada, H. , Gombos, Z. , Sakamoto, T. , and Murata, N. (1992) Genetic manipulation of the extent of desaturation of fatty acids in membránì lipids in the cyanobacterium *Synechocystis* PCC 6803. *Plant Cell Physiol* 33: 535-540.

Waditee, R. , Bhuiyan, Md. N. R. , Rai, V. , Aoki, K. , Tanaka, Y. , Hibino, T. , Suzuki, S. , Takáno, J. , Jagendorf, A. T. , Takabe, T. , and Takabe, T. (2005) Genes for direct methylation of glycine provide high levels of glycine betaine and abiotic stress tolerance in *Synechococcus* and *Arabidopsis*. *Proe Nati Acad Sci USA* 102:1318-1323.

Waditee, R. , Bhuiyan, Md. N. R. , Rrata, E. , Mbino, T. , Tanaka, Y. , Shikata, M. , and Takabe, T. (2007) Metabolic engineering of betaine accumulation in microbes and plants. *J Biol Chem* 282:34185-34193.

Waditee, R. , Rbino, T. , Tanaka, Y. , Nakamura, T. , Incharoensakdi, A. , and Takabe, T. (2001) Halotolerant cyanobacterium *Aphanothece halophytica* contains an Na⁺ /R antiporter, homologous to eukaryotic ones, wih novel ion specificity affected by C-terminal tail. *J Biol Chem* 276:36931-36938.

Waditee, R. , Rbino, T. , Nakamura, T. , Incharoensakdi, A. , and Takabe, T. (2002) Overexpression of a Na⁺/R antiporter confers salt tolerance on a freshwater cyanobacterium, making it capable of growth in sea water. *Proe Nati Acad Sci USA* 99: 4109-4114.

Waditee, R. , Rossain, G. S. , Tanaka, Y. , Nakamura, T. , Shikata, M. , Takáno, J. , Takabe, T. , and Takabe, T. (2004) Isolation and functional characterization of Ca²⁺/H⁺ antiporters from cyanobacteria. *J Biol Chem* 279: 4330-4338.

Waditee, R. , Tanaka, Y. , Aoki, K. , Rbino, T. , Jikuya, R. , Takáno, J. , Takabe, T. , and Takabe, T. (2003) Isolation and functional characterization of N-mehyltransferases hat catalyze betaine synthesis from glycine in a halotolerant photosynthetic organism *Aphanothece halophytica*. *J Biol Chem* 278:4932-4942.

Wang, R. L. , Postier, B. L. , and Burnap, R. L. (2002) Polymerase chain reaction-based mutageneses identify key transporters belonging to multigene families involved in Na⁺ and pH homeostasis of *Synechocystis* sp. PCC 6803. *Mol Microbiol* 44: 1493-1506.

Wang, J. C. , and Lynch, A. S. (1993) Transcription and DNA supercoiling. *Curr Opin Gene Dev* 3: 764-768.

Warr, S. R. C. , Reed, R. R. , and Stewart, W. D. P. (1987) Low-molecular weight carbohydrate biosynthesis and the distribution of cyanobacteria (Blue-Green Algae) inmarine environments. *Br Phycol J* 22:175-180.

Warr, S. R. C. , Reed, R. R. , Chùdek, J. A. , Foster, R. , and Stewart, W. D. P. (1985) Osmotic adjustment in *Spirulina platensis*. *Planta* 163: 424-429.

Webb, R. , Reddy K. J. , and Sherman, L. A. (1990) Regulation and sequence of the *Synechococcus* sp. strain PCC 7942 *groESL* operon, encoding a cyanobacterial chaperonin. *J Bacteriol* 172: 5079-5088.

Weber, M.R. , and Marahiel, M.A. (2003) Bacterial cold shock responses. *Sci Prog* 86: 9-75.

Welinder, K.G. (1992) Superfamily of plant, fungal and bacterial peroxidases, *Curr Opin Struct Biol* 2: 388-393.

Wells, W. W. , Yang, Y. , and Diets, T. L. (1993) Thioltransferases. *Adv Enzymol* 66:149-201.

White, O. , Eisen, J. A. , Heidelberg, J. F. , Rckey E. K. , Peterson, J. D. , Dodson, R. J. , Haft, D. R. , Gwinn, M. L. , Nelson, W. C. , Richardson, D. L. , Moffat, K. S. , Qin, R. , Jiang, L. , Pamphile, W. , Crosby M. , Shen, M. , Vamathevan, J. J. , Lam, P. , McDonald, L. , Utterback, T. , Zalewski, C. , Makarova, K. S. , Aravind, L. , Daly, M. J. , Minton, K.W. , Fleischmann, R. D. , Ketchum, K. A. , Nelson, K.E. , Salzberg, S. , Smih, H. O. , Venter, J. C. , and Fraser, C. M. (1999) Genome sequence of the radioresistant bacterium *Deinococcus radiodurans* RI. *Science* 286:1571-1577.

Whitton, B. A. (1982) *Rivers, Lakes and Marshes*. Hodder & Stoughton. London, UK. pp. 131.

Whitton, B. A. (1992) Diversity ecology and taxonomy of the cyanobacteria. In: Mann, N.R., and Carr, N.G., (Eds.) *Photosynthetic Prokaryotes*, Plenum Press , New York, N.Y. , USA. pp. 1-51.

Whitton, B. A. , and Potts, M. (2000) *Ecology of Cyanobacteria: Their Diversity in Time and Space*. Kluwer, Dordrecht, The Netherlands.

Whitton, B. A. , Donaldson, A. , and Potts, M. (1979) Nitrogenfixationby *Nostoc* colonies in terrestrial environments of Aldabra Atoll, Indián Oceán. *Phycologia* 18:278-287.

Wickner, S. , Gottesman, S. , Skowrya, D. , Hoskins, J. , McKenney K. , and Maurizi, M. R. (1994) Amolecular chaperone, ClpA., functions like DnaK and DnaJ. *Proe Nati Acad Sci USA* 91:12218-12222.

Wierzchos, J. , Ascaso, C. , and Mckay C. P. (2006) Endolithic cyanobacteria in halite rocks from hype rarid core of the Atacama Desert. *Astrobiology* 6: 415-422.

Wilken, C. , Kitzing, K. , Kurzbauer, R. , Ehrmann, M. , and Clausen, T. (2004) Crystal structure of the DegS stress sensor: how a PDZ domain recognizes misfolded protein and activates a protease. *Cell* 117: 483-494.

Williams, S. B. , and Stewart, V. (1999) Functional similarities among two component sensors and mehyl-accepting chemotaxis proteins suggest a role for linker region amphipathic helices in transmembrane signál transduction. *Mol Microbiol* 33: 1093-1102.

Willmsky, G. , Bang, H. , Fischer, G. , and Marahiel, M. A. (1992) Characterization of *cspB.*, a *Bacillus subtilis* inducible cold shock gene affecting cell viability at low temperatures. *J Bacteriol* 174: 6326-6335.

Wilson, N. W. , and Nierhaus, K. H. (2004) The how and Y of cold shock. *Nat Struct Mol Biol* 11:1026-1028.

Winterbourn, C. C. (2008) Reconciling the chemistry and biology of reactive oxygen species. *Nat Chem Biol* 4:278-286

Wojtkowiak, D. , Georgopoulos, C. , and ZyKcz, M. (1993) Isolation and characterization of ClpX., a new ATP-dependent specificity component of the Clp protease of *Escherichia coli*. *J Biol Chem* 268:22609-22617.

Wood, J. M. (1999) Osmosensing by bacteria: signals and membránì based sensors. *Microbiol Mol Biol Rev* 63:230-262.

Wood, Z. A. , Schroder, E. , Robin Harris, J. , and Poole, L. B. (2003) Structure, mechanism and regulation of peroxiredoxins. *Trends Biochem Sci.* 28: 32-40.

Wright, D. J. , Smith, S. C. , Joardar, V. , Scherer, S. , Jervis, J. , Warren, A. , Helm, R. R. , and Potts, M. (2005) UV-irradiation and desiccation modulate the three-dimensional extracellular matrix of *Nostoc commune* (cyanobacteria). *J Biol Chem* 280: 40271-40281.

Wutipraditkul, N. , Waditee, R. , Incharoensakdi, A. , Hibino, T. , Tanaka, Y. , Nakamura, T. , Shikata, M. , Takabe, T. , and Takabe, T. (2005) Halotolerant cyanobacterium *Aphanothece halophytica* contains NapA-type Na⁺/H⁺ antiporters with novel ion specificity that are involved in salt tolerance at alkaline pH. *Appl Environ Microbiol* 71: 4176-4184.

Xia, B. , Valmis-Gardikas, A. , Holmgren, A. , Wright, P. E. , and Dyson, H. (2001) Solution structure of *Escherichia coli* glutaredoxin-2 shows similarity to mammalian glutathione S-transferases. *J Mol Biol* 310: 907-918.

Xie, W. , Tice, D. , and Potts, M. (1995) Cell-water deficit regulates expression of *rpoCld* (RNA polymerase) at the level of mRNA in desiccation-tolerant *Nostoc commune* UTEX 584 (cyanobacteria). *FEMS Microbiol Lett* 126:159-164.

Xu, W. L. , Jeanjean, R. , Liu, Y. D. , and Zhang, C. C. (2003) *pkn22* (*alr2502*) encoding a putative Ser/Thr kinase in the cyanobacterium *Anabaena* sp. PCC 7120 is induced by both iron starvation and oxidative stress and regulates the expression of *isiA*. *FEBS Lett.* 553:179-182.

Yamamoto, H. , Miyake, C. , Dietz, K. J. , Tomizawa, K. , Murata, N. , and Yokota, A. (1999) Thioredoxin peroxidase in the cyanobacterium *Synechocystis* sp. PCC 6803. *FEBS Lett* 447: 269-273.

Yancey P. H. , Clark, M. E. , Hand, S. C. , Bowlus, R. D. , and Somero, G. N. (1982) Living with water stress: evolution of osmolyte systems. *Science* 217:1214-1222.

Yang, Y. , Yin, C. , Li, W. , and Xu, X. (2008) α -Tocopherol is essential for acquired chill-light tolerance in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 190:1554-1560.

Yin, C. , Li, W. , Du, Y. , Kong, R. , and Xu, X. (2007) Identification of a gene, *ccr-1* (*slll242*), required for chill-light tolerance and growth at 15°C in *Synechocystis* sp. PCC 6803. *Microbiology* 153:1261-1267.

Yoshida, T. , and Sakamoto, T. (2009) Water-stress induced trehalose accumulation and control of trehalose in the cyanobacterium *Nostoc punctiforme* IAM M-15. *J Gen Appl Microbiol* 55:135-145.

Yoshimura, K. , Yoshimura, T. and Esaki, N. (1998) Hsc62, a new DnaK homolog of *Escherichia coli*. *Biochem Biophys Res Commun* 250:115-118.

Yoshimura, H. , Ikeuchi, M. , and Ohmori, M. (2006) Up-regulated gene expression during dehydration in a terrestrial cyanobacterium, *Nostoc* sp. strain HK-01. *Microbes Environ* 21:129-133.

Yoshimura, H. , Okamoto, S. , Tsumuraya, Y. , and Ohmori, M. (2007) Group 3 sigma factor gene, *sig*, a key regulator of desiccation tolerance, regulates synthesis of extracellular polysaccharide in the cyanobacterium *Anabaena* sp. strain PCC 7120. *DNA Res* 14:13-24.

Youn, H.-D. , Yim, Y.-L. , Kim, K. , Hah, Y. C. , and Kang, S.-O. (1995) Spectral characterization and chemical modification of catalase-peroxidase from *Streptomyces* sp. *J Biol Chem* 270:13740-13747.

Youn, H. D. , Youn, H. , Lee, J. W. , Yim, Y. I. , Lee, J. H. , Hah, Y. C. , and Kang, S.-O. (1996) A novel nickel-containing superoxide dismutase from *Streptomyces* spp. *Biochem J* 318: 889-896.

Yousef, N. , Pistorius, E. K. , and Michel, K.-P. (2003) Comparative analysis of *idiA* and *isiA* transcription under iron starvation and oxidative stress in *Synechococcus elongatus* PCC 7942 wild-type and selected mutants. *Arch Microbiol* 180: 471-483.

Yu, E. , and Owtrim, G. W. (2000) Characterization of the cold stress-induced cyanobacterial DEAD-box protein CrhC as an RNA helicase. *Nucleic Acids Res* 28:3926-3934.

Yura, T. , Kanemori, M. , and Morita, M. T. (2000) The heat shock response: regulation and function. In: Storz, G., and Hengge-Aronis, R. (Eds.), *Bacterial Stress Responses*. ASM. Press, Washington, DC. USA. pp. 3-18.

Zach, A. , Adi, I. , Galit, S.-V. , and Wataru, S. (2005) FtsH proteases in chloroplasts and cyanobacteria. *Physiol Plant* 123: 386-390.

Zak, E. , Norling, B. , Maitra, R. , Huang, R. , Andersson, B. , and Pakrasi, H. B. (2001) The initial steps of biogenesis of cyanobacterial photosystems occur in plasma membranes. *Proc Natl Acad Sci USA* 98:13443-13448.

Zámocký, M. (2004) Phylogenetic relationships in class I of the superfamily of bacterial, fungal and plant peroxidases. *Eur J Biochem* 271: 3297-3309.

Zámocký, M. , Furtmüller, P. G. , and Obinger, C. (2008) Evolution of catalases from bacteria to humans. *Antioxid Redox Signál* 10:1527-1547.

Zámocký, M. , Furtmüller, P. G. , and Obinger, C. (2010) Evolution of structure and function of class I peroxidases. *Arch Biochem Biophys* 500:45-57.

Zámocký, M. , Regelsberger, G. , Jakopsch, C. , and Obinger, C. (2001) The molecular peculiarities of catalase-peroxidases. *FEBS Lett* 492:177-182.

Zeng, M. T. , and Vonshak, A. (1998) Adaptation of *Spirulina platensis* to salinity stress. *Comp Biochem Physiol* 120:113-118.

Zheng, M. , Aslund, R. , and Storz, G. (1998) Activation of the OxyR transcription factor by reversible disulfide bond formation. *Science* 279:1718-1721.

Zeh, K. , Offermann, S. , Essen, L. O. , and Oesterhelt, D. (2004) Iron-oxo clusters biomineralizing on protein surfaces: structural analysis of *Halobacterium salinarum* DpsA in its low- and high-iron states. *Proc Natl Acad Sci USA* 101:13780-13785.

Zhang, L.-E. , Yang, H.-M. , Cui, S.-X. , Hu, I. , Wang, I. , Kuang, T.-Y. , Norling, B. , and Huang, E. (2009) Proteomic analysis of plasma membranes of cyanobacterium *Synechocystis* sp. strain PCC 6803 in response to high pH stress. *J Proteome Res* 8: 2892-2902. doi: 10.1021/pr900024w

Zhang, T. , Gong, H. , Wen, X. , and Lu, C. (2010) Salt stress induces a decrease in excitation energy transfer from phycobilisomes to photosystem II but an increase to photosystem I in the cyanobacterium *Spirulina platensis*. *J Plant Physiol* 167:951-958.

Zhao, J. D. , and Brand, J. J. (1988). Sequential effects of sodium depletion on photosystem II in *Synechocystis*. *Arch Biochem Biophys* 264: 657-664.

Zhao, W. , Guo, Q. , and Zhao, J. (2007) A membrane-associated Mn-superoxide dismutase protects the photosynthetic apparatus and nitrogenase from oxidative damage in the cyanobacterium *Anabaena* sp. PCC 7120. *Plant Cell Physiol* 48: 563-572.

Zhu, X. , Zhao, X. , Burkholder, W. E. , Gragerov, A. , Ogata, C. M. , Gottesman, M. E. , and Hendrickson, W. A. (1996) Structural analysis of substrate binding by the molecular chaperone DnaK. *Science* 272:1606-1614.

Zolkiewski, M. (1999) ClpB cooperates with DnaK, DnaJ and GrpE in suppressing protein aggregation. A novel multi-chaperone system from *Escherichia coli*. *J Biol Chem* 274: 28083-28086.

Zuther, E. , Scubert, H. , and Hagemann, M. (1998) Mutation of a gene encoding a putative glycoprotease leads to reduced salt tolerance, altered pigmentation and cyanophycin accumulation in the cyanobacterium *Synechocystis* sp. strain PCC 6803. *J Bacteriol* 180:1715-1722.